BOILER ACCESSORIES

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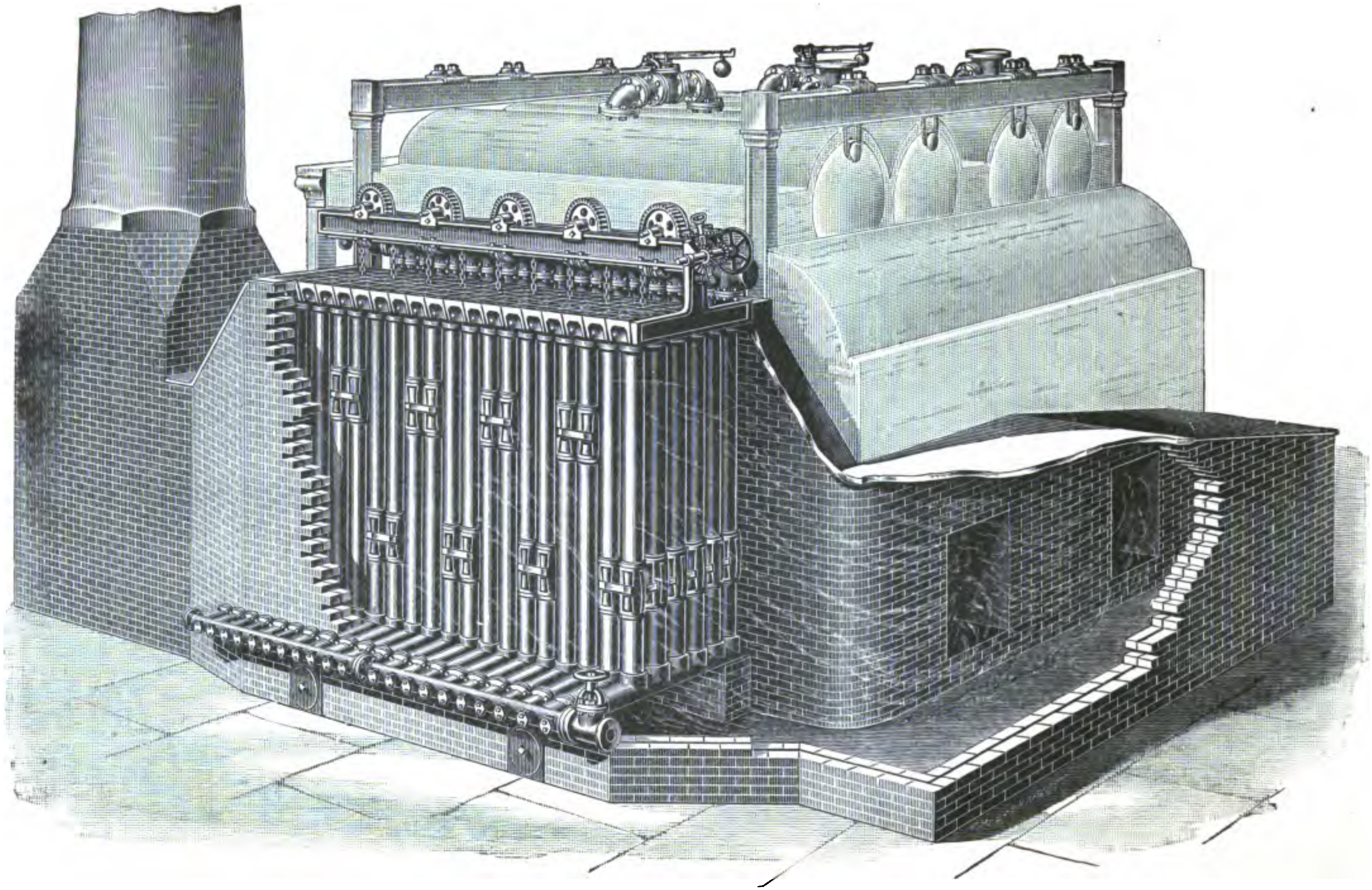

GREEN FUEL ECONOMIZER

Boiler Accessories

A Complete and Authoritative Treatise

ON THE VARIOUS ACCESSORIES OF THE BOILER ROOM AND ENGINE ROOM ESSENTIAL TO ECONOMICAL OPERATION, TOGETHER WITH PRACTICAL INSTRUCTION IN THEIR USE

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ILLUSTRATED

CHICAGO
AMERICAN SCHOOL OF CORRESPONDENCE
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Foreword

IN recent years, such marvelous advances have been made in the engineering and scientific fields, and so rapid has been the evolution of mechanical and constructive processes and methods, that a distinct need has been created for a series of *practical working guides*, of convenient size and low cost, embodying the accumulated results of experience and the most approved modern practice along a great variety of lines. To fill this acknowledged need, is the special purpose of the series of handbooks to which this volume belongs.

In the preparation of this series, it has been the aim of the publishers to lay special stress on the *practical* side of each subject, as distinguished from mere theoretical or academic discussion. Each volume is written by a well-known expert of acknowledged authority in his special line, and is based on a most careful study of practical needs and up-to-date methods as developed under the conditions of actual practice in the field, the shop, the mill, the power house, the drafting room, the engine room, etc.

These volumes are especially adapted for purposes of self-instruction and home study. The utmost care has been used to bring the treatment of each subject within the range of the common understanding, so that the work will appeal not only to the technically trained expert, but also to the beginner and the self-taught practical man who wishes to keep abreast of modern progress. The language is simple and clear; heavy technical terms and the formulæ of the higher mathematics have been avoided, yet without sacrificing any of the requirements of practical instruction; the arrangement of matter is such as to carry the reader along by easy steps to complete mastery of each subject; frequent examples for practice are given, to enable the reader to test his knowledge and make it a permanent possession; and the illustrations are selected with the greatest care to supplement and make clear the references in the text.

¶ The method adopted in the preparation of these volumes is that which the American School of Correspondence has developed and employed so successfully for many years. It is not an experiment, but has stood the severest of all tests—that of practical use—which has demonstrated it to be the best method yet devised for the education of the busy working man.

¶ For purposes of ready reference and timely information when needed, it is believed that this series of handbooks will be found to meet every requirement.

Table of Contents

MANHATTAN 74TH ST. POWER STATION, NEW YORK.
Showing Carey's Magnesia Pipe and Boiler Covering.

BOILER ACCESSORIES

PART I

BOILER SETTING

The *setting* for a stationary boiler consists of the foundation and as much of the furnace and flues as is external to the boiler shell. Some internally-fired boilers—the "Lancashire," for instance—have flues in the brick setting. The whole furnace and sometimes the flues, as is the case with the plain cylindrical boiler, are in the setting. Vertical boilers have simply a foundation; and locomotive boilers have no setting, since they are supported by the frames of the engines. Marine boilers are usually placed on saddles, which are built into the framing of the vessel.

In setting a boiler, there are three principal requisites that should be kept in mind: 1. A stable support or foundation for the shell, so arranged as to allow for proper expansion of the boiler. 2. Properly arranged spaces for both furnace flues and ash-pit. 3. A covering which will prevent loss of heat by radiation, and which will not allow moisture to accumulate in contact with the plates.

There are two principal methods for support—by *brackets* riveted to the shell plates, and by *suspension from overhead girders* by means of hooks, rings, etc. In any case the supports should be so arranged that each shall bear its proper proportion of the load and at the same time allow for expansion. If the boiler is short, brackets are generally used; while for long, plain cylindrical boilers the girder method is the more common. If a very long, cylindrical boiler is supported only at each end, the great weight between the two supports is likely to cause bending and an excessive strain on the middle plates, tension in the bottom plates, and compression in the top plates.

The first requisite for a setting is a good *foundation*. If the ground is firm and favorable to a solid foundation, the excavation need be only three or four feet below the level. If it is soft, the excavation should be deeper, and the extra depth filled in with broken stone mixed in with cement, gravel, etc.; or, for very heavy work, piles may be driven. The first course of the foundation should be large stones laid in cement; upon this stonework the walls may be built, either of stone or brick, to within about six inches of the floor-level; and above this, brick should be used.

Sometimes the bed is made of concrete about two feet in thickness. If the soil is very firm, a foundation of large stonework about three feet wide may be built under the side, middle, and end walls only.

In determining the *area* of the bed, the weight that is to be put on each square foot should be estimated carefully. With ordinary condition of the soil, this should not exceed 2,000 pounds. For greater weights, special construction must be used.

The *supporting* and *enclosing* walls are built upon the foundation, with the outer walls at the sides and rear double, the space between, usually about two inches, being an air-space insulation to prevent loss of heat. Projecting bricks, which extend from the outer until they just touch the inner wall, allow for expansion without decreasing the strength of the inner wall. The side walls are strengthened by buck-stays or binders, which are kept in place by long bolts, secured by nuts on each end. Fig. 1 shows a boiler in the brick setting, supported by brackets, the front brackets resting on iron plates which are built into the walls; the rear brackets, being supported by rollers, are free to move as the shell expands. If designed for anthracite coal, the distance between the shell and the grate-bars is about two feet; for softer coal, this distance is increased a few inches.

The furnace is lined with firebrick, both front and sides; and sometimes portions back of the bridge, as well as the bridge itself, may thus be protected. The space between the bridge and the shell is from 6 to 8 inches, which brings the hot gases into close contact with the boiler before they enter the combustion chamber beyond, the rear and side walls being built a little higher than the top row of tubes. The fire-line must not be carried above the water-line; if it is, the intense heat is likely to injure the shell-plates. Never expose any part of the boiler not covered by water to the flames from the furnace. The side walls are built about the same height as the rear walls. The space at the rear is bridged over and stiffened by T-irons. In order to increase the heating surface, the top is arched so that the hot gases will pass over the steam space before they enter the chimney.

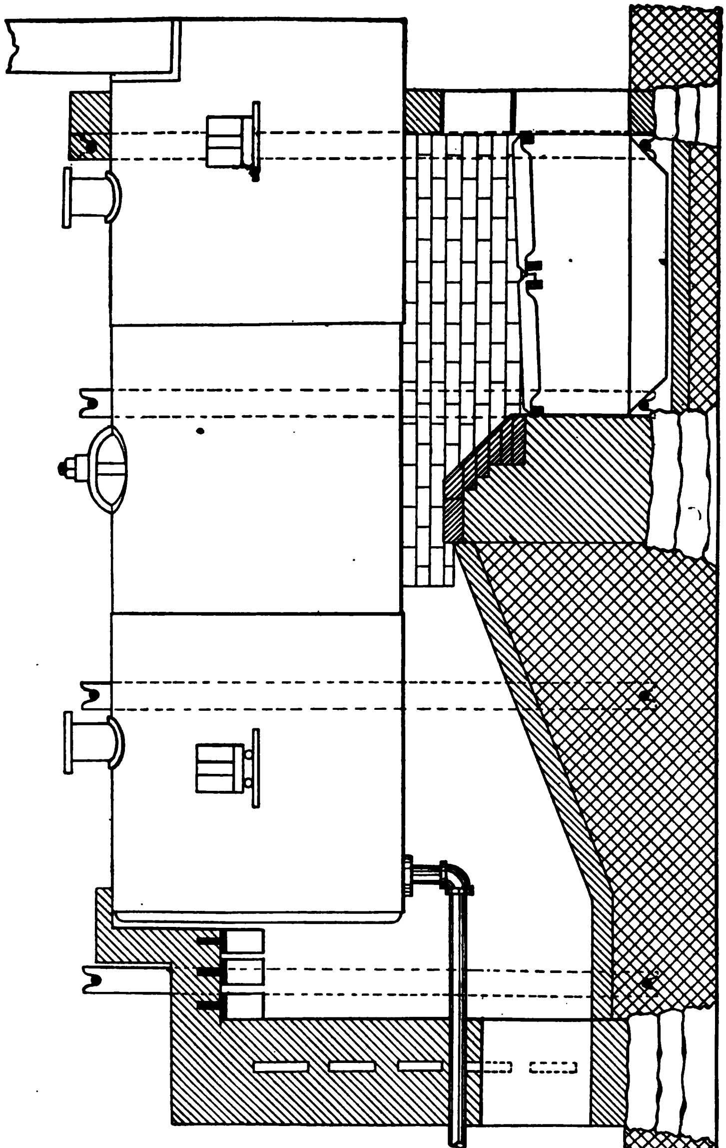


Fig. 1. Side Elevation of Boiler in Brick Setting.

The smoke box projects over the front end of the boiler and has a rectangular uptake.

Fig. 3 shows the top view of the same boiler.

The front is usually of cast iron, with doors for firing and cleaning and for access to the tubes. Soot, dirt, etc., are removed through the door in the brickwork at the rear.

The end which contains the handhole should be set about one

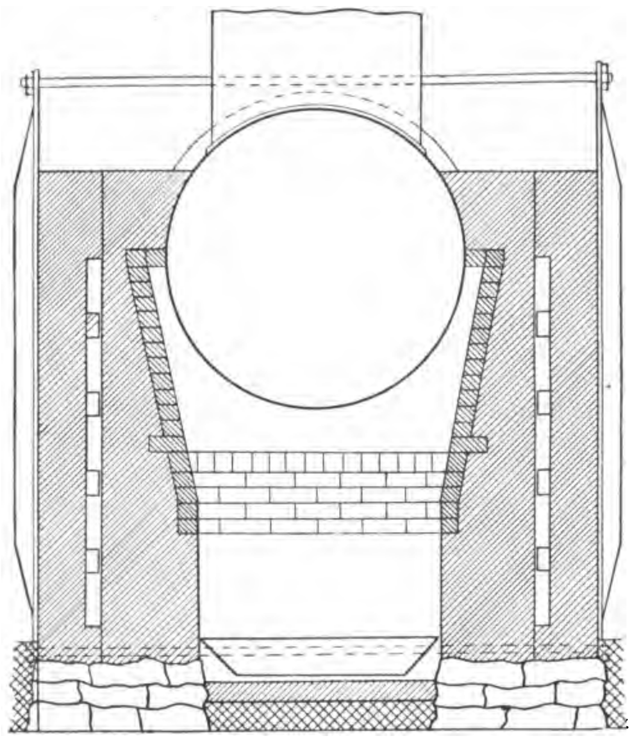


Fig. 2. Front Elevation of Boiler in Setting, Showing Binders Bolted in Place, to Strengthen Side Walls.

inch *lower* than the other end, so that the sediment and detached scale will tend to accumulate there.

Internally-fired boilers may also be enclosed in brickwork. The setting is a support and covering, forming the side flues but not the furnace. Excess of brickwork surface in contact with the shell, should be avoided, as brickwork collects moisture, which causes external corrosion.

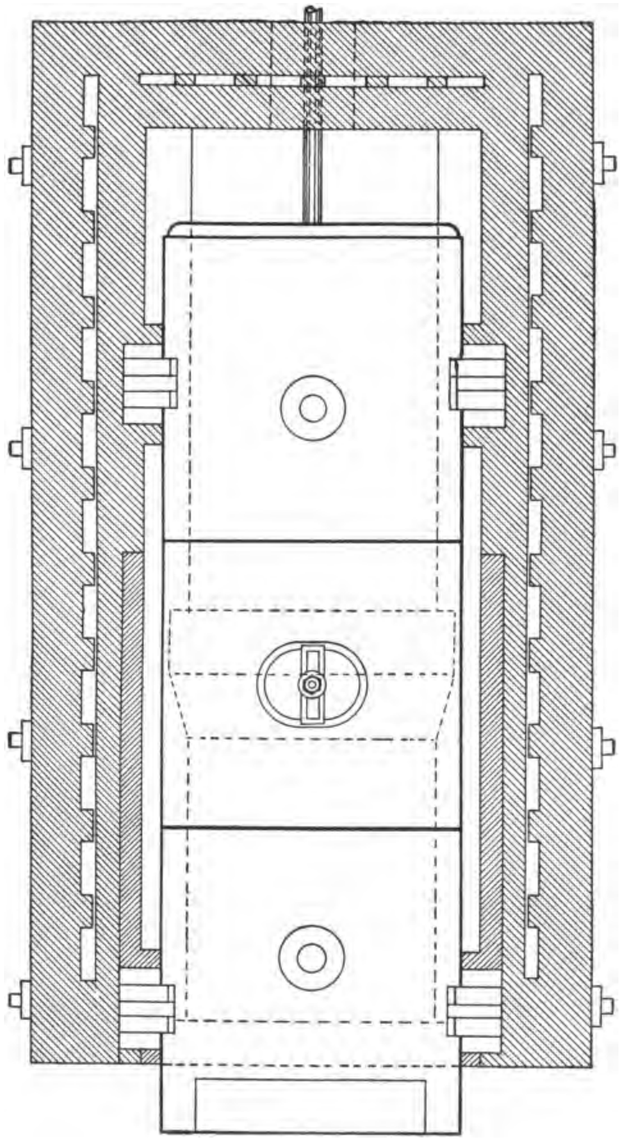


Fig. 3. Plan of Boiler and Setting.

Water-Tube Boilers. The settings for water-tube boilers are similar to the settings of cylindrical tubular boilers. Marine water-

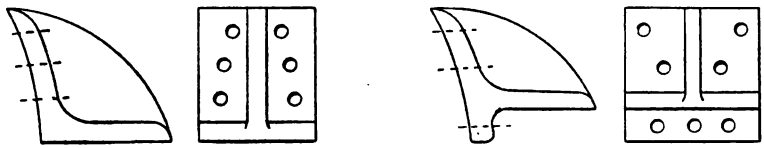


Fig. 4. Fig. 5.

Types of Brackets for Supporting Boilers.

In Fig. 4 the rivets are all above the flange; in Fig. 5 they are both above and below the flange.

tube boilers are enclosed in sheet-iron casing, which is lined with non-conducting material, usually asbestos or m agnesia.

Supports. There are, as already intimated, two common methods of supporting boilers—1. By means of *brackets*; 2. By *suspending from wrought-iron beams.*

If the boiler is about 15 feet long, it is customary to use two brackets on each side. If more than 15 feet, three on each side are used. The front brackets rest on the brickwork, but the others rest on small iron rollers to allow for expansion. Brackets are so arranged that the plane of support will be a little above the middle. There are several forms of brackets. The form shown in Fig. 4 is usually made of cast iron, and is provided with rivets above the flange of the bracket.

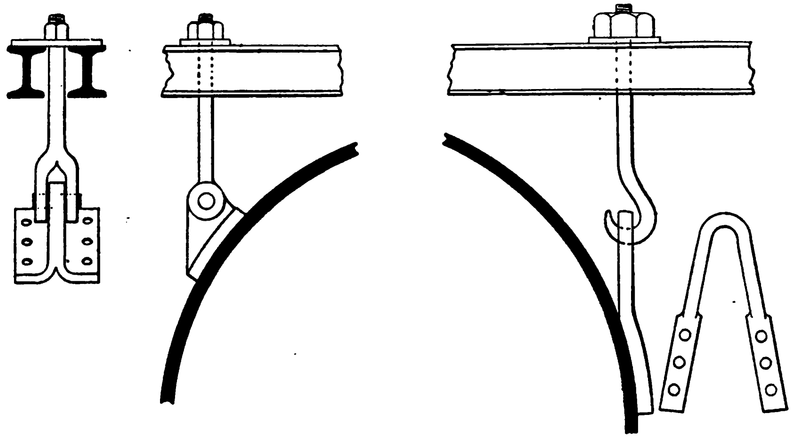


Fig. 6. Fig. 7.

Two Methods of Supporting Boilers by Suspending from Overhead Beams.

It is better to have the rivets both above and below the flange, as shown in Fig. 5.

Fig. 6 shows one method of suspending from beams. A lug, made of wrought iron, is riveted to the plates of the boiler. A bolt having one end bent like a hook, holds the lug from the beam. In Fig. 7 the lug is replaced by a loop of wrought iron. Fig. 8 shows another method of suspension, the connection between the rod and the boiler-plates being short pieces of boiler-plate arranged for flexibility.

When the boiler is of small diameter, it may be suspended as shown in Fig. 9.

FURNACES

To get the maximum efficiency from any boiler, it is necessary that the fuel shall be properly consumed, and that the proportions

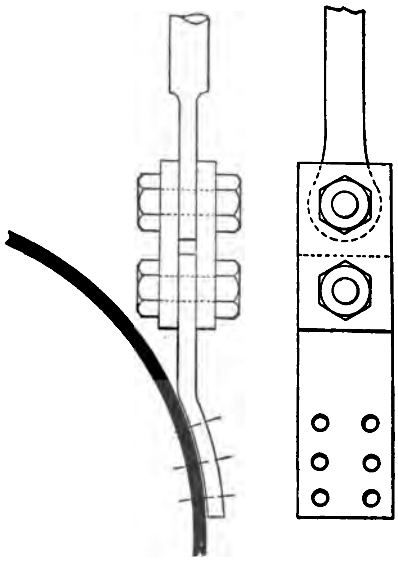


Fig. 8. Flexible Support for Suspended Boiler. Flexibility Secured by means of Two Pieces of Boiler-Plate Bolted Together.

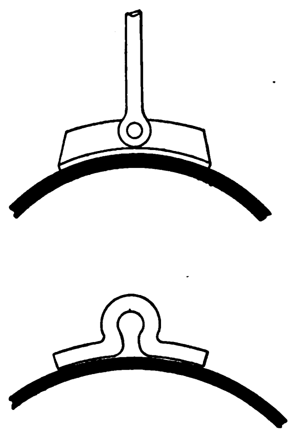


Fig. 9. Illustrating Method of Suspending Boiler of Small Diameter.

of the furnace shall be such as to give the maximum results. No boiler is economical the furnace of which is so small that the fire has to be forced to obtain the desired result. The furnace, of course, will vary in shape, size, and detail with the type of boiler and the kind of fuel; but certain essentials—such as doors, grate-bars, bridge, and ash-pit—are similar in all furnaces. To obtain the maximum efficiency of combustion, there should be a uniform and abundant supply of air to the under side of the grate. This is easily obtained when the boilers are externally fired, but may be somewhat restricted when they are internally fired. If smoky fuels are used, a moderate supply of air is necessary on the surface of the coal, to prevent excessive smoke formation; but, as the air thus admitted is usually cold, the quantity should be small, to prevent unnecessary cooling of the furnace. This air is generally supplied through a draft-plate in the fire-door.

All possible radiation should, of course, be prevented. In the case of internally-fired boilers, this radiation is not likely to be excessive, for most of the heat would have to pass through the water in the boiler before radiating, and it is a comparatively easy matter to encase such a boiler in some sort of approved lagging which will prevent most of the heat from escaping. The case is somewhat different with the externally-fired boiler, where the furnace is built in a mass of brickwork below the boiler. In such a furnace a considerable amount of heat may radiate directly from the fire without coming in contact with the boiler or water at all.

To allow for complete combustion, there should be a sufficient space between the grate and the boiler. In externally-fired boilers, this space may be approximately two feet. If this distance is increased beyond proper limits, some effect of the heat will be lost; and if the distance is small, the plates are likely to be damaged, and complete combustion impaired. In the internally-fired boiler, the combustion space is frequently sacrificed in order to obtain a large grate area. If the space between the grate-bars and the boiler is too small to allow complete combustion, a combustion chamber must be provided immediately back of the bridge, which will permit of the complete combustion of the gases. The ideal place, of course, for the combustion chamber, is immediately over the grate. In locomotive boilers, the crown sheet is usually four to six feet above the grate; but such a height is manifestly impossible in marine or other internally-fired boilers, and the combustion chamber behind the bridge wall, in the Scotch boiler, partially compensates for the loss of space immediately over the grate.

The incandescent fuel and unconsumed gases should not come in contact with the cold surfaces of the boiler if the most efficient combustion is desired. This condition is violated in internally-fired boilers, where the fire comes directly against metal having water on one side of it. If the flame is chilled by contact with cold surfaces before the gases are completely burned, a considerable amount of smoke is likely to result.

The fire-grate should be of such dimensions that the fireman can work efficiently. A grate more than six feet long cannot be properly taken care of at the farther end; and if the grate is more than four feet wide, two fire-doors should be provided. The height of the grate should be laid out with proper reference to the floor, two feet above the floor being about right. If the grate is high, it is difficult, if not impossible, to tend the fire properly. These conditions are dependent, not so much upon the boiler, as upon the physical limitations of the fireman, and of course are eliminated by using the mechanical stoker.

To the above conditions may be added a suitable temperature in the fire-room. No man can tend a fire properly in excessive heat. In stationary work it is not difficult to maintain proper conditions in the fire-room; but at sea, where the supply of air is necessarily limited to what can come in through small openings, it is a different problem. The fire space on board ship is small; and the air coming through the ventilating ducts usually makes an exceedingly cold spot immediately under the duct without producing much effect in other parts of the room.

Door. The furnace door is usually made of cast iron, and is supplied with a circular or sliding draft-plate or *grid*, which admits air to the top of the fire as needed. It is usually protected by a perforated, wrought-iron baffle-plate bolted to the door casting inside, with an air-space of two or three inches between. This not only protects the cast iron of the door from the direct force of the flame, but it forms a chamber for the proper distribution of the air-supply, and also helps to heat it somewhat before reaching the furnace.

In many of the French torpedo-boats, a patent swinging door is provided, set on horizontal hinges swinging inwards. The door, of course, must be held open while the stoker is tending the fire; but in case a tube blows out, it prevents the rapid escape of steam into the fire-room. This is a matter of much more importance in the restricted fire-room commonly found on a vessel than it would be on land.

Grate. The size of grate will depend upon the quantity of coal likely to be burned. For ordinary draft, this may be 15 lbs. or upward per square foot of grate surface per hour; for forced draft, 40 to 60 lbs.; and in some cases as much as 100 lbs. per square foot of grate surface has been burned. If the grates are long, they are usually inclined slightly downwards, say $\frac{3}{4}$ inch to the foot, which is a great assistance in firing and makes it easier to keep fire on the farther end of the grate.* The grate-bars are usually made of cast iron, as this material is cheaper than wrought iron and in most instances lasts as well. The bars are made in various forms, according to the fuel burned and the shape of the firebox.

For large grates, the bars are made singly or in pairs. For smaller grates, they are made in larger groups. Grate-bars should not be more than three feet in length. The length of grate can easily be a multiple of the length of these bars. The bars have distance pieces at the ends, and perhaps in the middle, to prevent distortion. They are usually 3 inches or more in depth at the middle, tapering to perhaps an inch or so at the ends; and the cross-section is slightly tapered from top to bottom, so that the bars can easily be withdrawn from the sand after casting. They are usually made a trifle shorter than the place in which they fit, to allow for expansion, 2 per cent of the length of the bar usually being sufficient for this purpose. The air-spaces between the bars are usually about $\frac{1}{2}$ inch in width. For burning pea coal or screenings, a finer grate must be used. For anthracite coal, the space may be a little larger. Bituminous coal, which readily cakes, can have a considerable space between the bars—and this, indeed, is essential for a proper supply of air.

Fig. 10 shows a circular grate, such as is placed in a vertical boiler. *M* shows the style of grate-bar used in burning sawdust or shavings; *N* is what is known as the *herring bone* grate; and *O* is a group of bars of the ordinary form. In locomotives, and in boilers where the grates are subjected to extra hard usage, wrought-iron bars may be used. The point of fusion of wrought iron being higher than that of cast iron, the former would possess a considerable advantage were it not for the fact that wrought iron will bend and twist more readily than cast iron. Grates have been made of hollow bars, through which water is caused to circulate. By this method their

* The grates have an incline of a few inches, so that the bed of coal will be thicker at the rear than at the front; this allows a more even consumption of fuel, as the air passes through the fire at the bridge more freely.

durability is increased, and the *water-grate* forms a fairly good feed-water heater. This type of grate, however, is expensive.

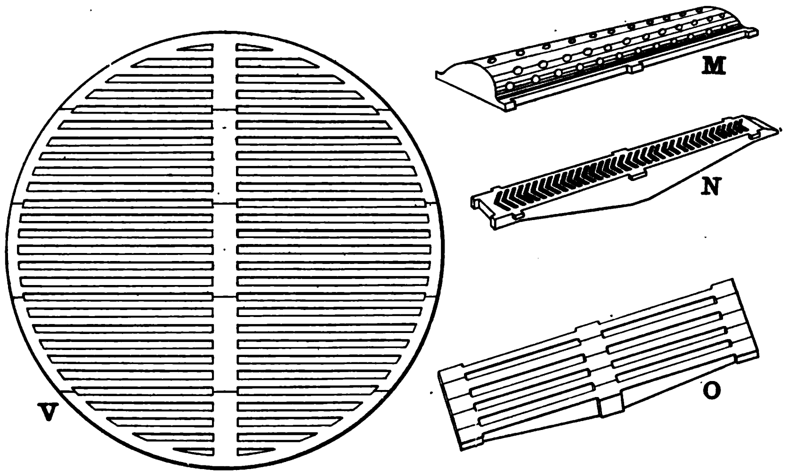


Fig. 10. Types of Grates for Boilers. *V*—Circular Grate for Vertical Boiler; *M*—Grate for Burning Sawdust or Shavings; *N*—"Herring-Bone" Grate. *O*—Group of Grate-Bars of Ordinary Form.

Rocking Grates. The labor of breaking the clinkers is considerable when ordinary fixed grate-bars are used; and to economize this labor, various forms of rocking-grates have been devised. In

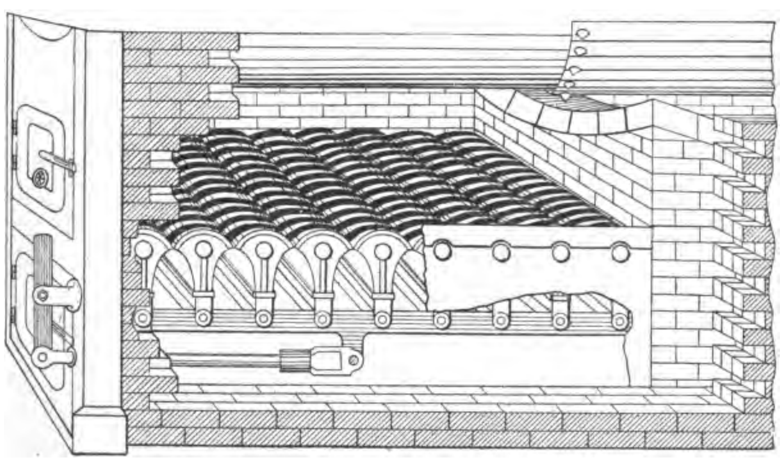


Fig. 11. "Kelley Standard" Rocking Grate.

locomotives, rocking-grates are essential; and since the rate of combustion is high, the fire must always be kept in good condition; and the grate, being below the cab floor, cannot easily be reached by hand. Fig. 11 shows the "Kelley Standard" rocking grate. Each bar is made up of a number of separate leaves, which can be removed and replaced without renewing the whole bar. When the bar is moved back and forth by means of a lever outside the brickwork, the leaves oscillate through a small angle and break up the clinkers.

Another form of bar, shown in Fig. 12, has proved very satisfactory. *A* and *B* are two bars, the ends of which are of different depths. These rest at each end on a crank-shaft *C*. As this is oscillated by the lever *G*, the alternate bars move up and down, and the clinkers are easily shaken out.

Bridge. The bridge is a large wall or partition at the back of the

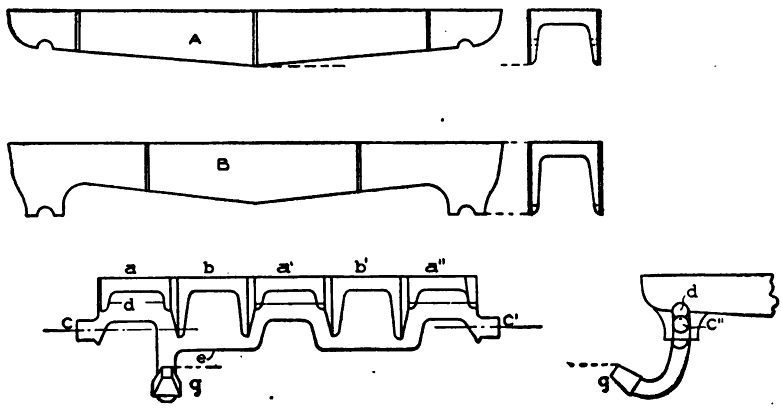


Fig. 12. Rocking Grate Consisting of Alternate Bars with Ends of Different Depths Resting on a Crank-Shaft Oscillated by a Lever.

grate, usually built of firebrick or cast iron, or of ordinary brick covered with firebrick. The bridge separates the grate from the combustion chamber, and causes the gases to come in close contact with the boiler in passing into the combustion chamber. The proper height of the bridge will depend upon the draft. If the space is narrow between the bridge wall and the boiler, more draft will be necessary to carry the gases through. Two or more bridges may sometimes be built in long boilers to keep the gases in contact with the shell as long as possible.

Special Furnaces. Almost any furnace is adapted for the use of anthracite or bituminous coal containing less than 20 per cent of volatile matter; but if there is more than this amount of volatile matter, the heat is likely to be so intense that the fire should not be brought in direct contact with the boiler. If the fuel should contain 40 per cent of volatile matter, the furnace should be surrounded with firebrick and should have a high combustion chamber. Coal is the most common fuel used; but wood, sawdust, and straw are not uncommon fuels. When these are burned, there should be plenty of room in the furnace, and a sufficient supply of air on top of the fuel. Sawdust, shavings, and fine coal may be blown into the furnace by an air-blast.

In the West, crude petroleum is becoming a common fuel. Experiments have shown that one pound of crude oil is equivalent in heat units to something less than two pounds of good coal. Oil has many advantages as a boiler fuel. It is clean, gives a uniform heat, is economical, and requires much less attention than coal. There are no ashes to handle, and one man can easily tend two or three times the number of furnaces that he could if burning coal. The fire can be started and stopped instantly; and the supply of air can be so regulated that, unless the boiler is forced to the limit, there will be practically no production of smoke. Whether or not oil is an economical fuel, will depend upon the local conditions and the market.

Oil fuel is fed into the furnace through a sprayer formed, in some cases of two concentric conical tubes. Compressed air or steam entering through the one tube draws the oil through the other, on the principle of the atomizer, and throws it into the furnace in a fine spray. For marine work, compressed air should be used, as the loss of steam for this purpose would be a matter of considerable consequence. Steam, however, is sometimes used in marine work, in which case the vessel must be equipped with an evaporator to make up the steam thus lost. On land, where fresh water is plenty, steam is usually preferred, and is less expensive in first cost.

Prevention of Smoke. In large cities, where the escape of considerable quantities of smoke is undesirable, several methods have been devised either to consume the smoke or to prevent its formation. The cause of smoke, as we have seen, is an insufficiency in the supply of air, or perhaps a too abundant supply of cold air above the fire; or, again, smoke may be due to the contact of the flame with cold surfaces. An exceedingly high temperature is necessary to consume the finely divided particles of carbon, and anything that tends to chill the flame will cause smoke.

The actual loss caused by the escape of smoke, even when it is dense and black, has been found to be slight, and usually the appliance used for prevention costs more than is saved. The alternate firing of two furnaces which open into a common combustion chamber, or the alternate firing of two sides of the same furnace, produces a slight gain if the proper amount of air is admitted. But if, in order to burn the smoke, the bed in one furnace or on one side of a furnace is allowed to become thin, there will be no gain in efficiency.

The introduction of steam is an efficient method, but it is likely to cause a too rapid rate of combustion.

Another arrangement to prevent the escape of smoke is that by

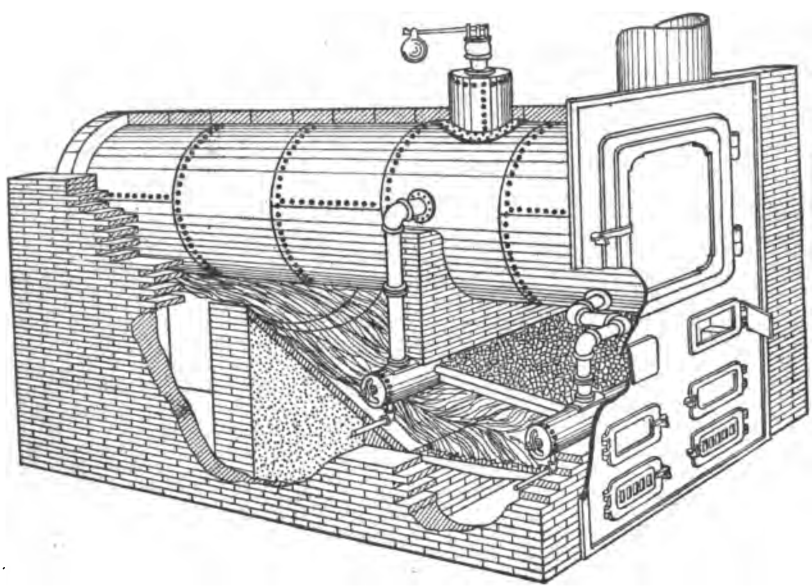


Fig. 13. "Hawley" Down-Draft Furnace Attached to Horizontal Multitubular Boiler. Note Upper Grate Consisting of Water Tubes Connected to Steel Drums.

which the coal is distilled in a small furnace which is separate from the boiler. The coke and gases thus made are burned in the furnace of the steam boiler. This device is not altogether satisfactory, on account of the loss of heat from the detached furnace. Rather than add any smoke-prevention device, anthracite or coke may be used instead of bituminous coal.

Many engineers and business men consider *a good fireman* to be the best smoke preventer.

Down-Draft Furnaces. In order to increase economy and capacity, or to prevent smoke, a down-draft furnace is sometimes used. In this type of furnace, there are two grates, one a foot or more above the other. Fresh coal is fed to the upper grate, and, as it becomes partially consumed, falls through to the grate below, where the combustion is completed. The draft is *downward* through the upper grate, and *upward* through the lower, because the connection to the chimney is from the space between the grates. The volatile gases are carried down through the bed on the upper grate, and are burned in the space below it, where they meet the hot air drawn upward from the lower grate. A large proportion of the air for combustion enters the door at the upper grate. Tests on the Hawley furnace show that 30 to 45 pounds of coal per square foot per hour can be burned with good results.

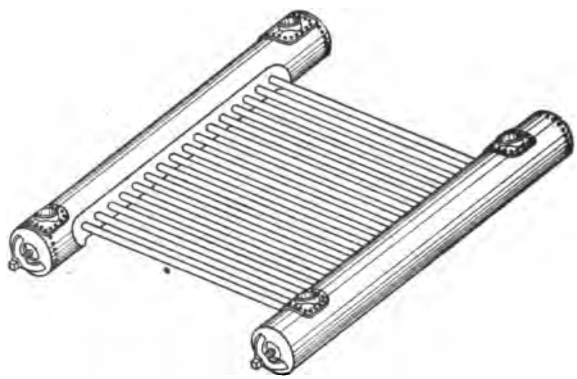


Fig. 14. Upper Grate of "Hawley" Down-Draft Furnace. The Grate-Bars are Water Tubes Connected to Steel Drums which are Connected to Boiler.

In the furnace made by the Hawley Down-Draft Boiler Company, the grates are formed of a series of water tubes opening at the ends into steel drums, shown in Figs. 13 and 14, which are connected with the boiler. Fig. 13 shows this furnace attached to a horizontal, multitubular boiler. It may be applied to both *tubular* and *water-tube* boilers with good results, and is advantageous to boilers of insufficient heating surface, and when inferior fuels are burned. It is claimed that this attachment insures complete combustion, small amount of ashes on account of the second grate, good water circulation, and increased economy and capacity.

The Hollow Arch. Among boiler accessories specially adapted for use on locomotives because of their intense draft, the hollow arch has recently come into prominence. Its principle is simply that of a conduit providing a passage for the admission of heated air to the firebox above the fire, in addition to the air that comes up through the grate from below in the ordinary way. Its object is to keep the supply of oxygen at all times sufficient in quantity, and at the proper temperature, to insure a practically perfect combustion of the unconsumed carbon and hydrocarbon gases which are ordinarily wasted and lost in the form of black smoke pouring from the stack. It thus insures an economy of fuel and a proportional reduction in operating expense.

The problem of securing complete combustion of fuel on a locomotive, is one that presents peculiar difficulties. The quantity of fuel to be burned is so large, and the firing space relatively so small, that the conditions usually are unfavorable for economical combustion. A ton of average bituminous coal contains about 1,000 pounds of pure carbon, 700 pounds of hydrocarbon gases, and 300 pounds of noncombustible matter or ash. The 1,700 pounds of carbon and hydrocarbons require about 300,000 cubic feet of air for their complete combustion. In the ordinary method of burning coal on a locomotive, fully 90 per cent of this air—or 270,000 cubic feet per ton of fuel burned—must be drawn up through the grate-bars and firebed. This is practically impossible without forcing the draft to such an extent that the fire will be pulled off the grates, and more or less of the unburned coal carried away through the flues and stack. The result is that the supply of air actually used is, as a general thing, insufficient for perfect combustion, and the combustible carbon smoke and gases pass out of the stack without giving up all of their heat to the water in the boiler. The energy they contain is simply wasted.

How, then, can this be prevented? In other words, since the quantity of air that comes through the grates is insufficient, how can we get enough air to the fuel without interfering with the fire? It must be let in *above the fire*; but it will not do to admit cold air, which, as every fireman knows, would act as a damper on the fire, retarding combustion, and increasing rather than preventing smoke and loss of energy. The air to be admitted to the fire must first be *heated to as near the ignition point as possible.*

This is done by means of the *hollow arch.* One of these arches of the "Wade-Nicholson" type, installed on a locomotive, is illustrated in Fig. 15, the method of operation being clearly indicated. The device may be installed at both back and front ends of the firebox.

The hollow passage through the arch leads directly through suitable openings in the firebox sheets, from the outer air to the combustion chamber, being deflected downward toward the fire at the inner end. The walls of the arch, being highly heated, impart their heat to the current of air, which, as it emerges into the firebox, is practically at the temperature of ignition. There mingling directly with the combustible gases, an approximately perfect combustion is established. The resulting economy in fuel is estimated to average a saving of at least 8 per cent.

Fig. 15. Wade-Nicholson Hollow Arch Installed in Locomotive Boiler. The Water-Tube Supports Here Shown are Sometimes Omitted.

The Chicago & Northwestern Railway, has, after severe test, adopted arches of the above type on over 200 of its locomotives; and its example has been followed on many of the locomotives of the Santa Fé, the Chicago, Milwaukee & St. Paul, the Père Marquette, the Duluth & Iron Range, and other important railroads in this country. In addition to the saving in fuel, the following advantages are claimed for the hollow arch:

Being air-cooled, its life is two to three times that of the ordinary solid brick arch.

It does away with the smoke nuisance.

The air, being heated before striking the combustible gases, unites with them instantly, giving a brighter, cleaner, more intense fire, and resulting in a better steaming engine.

The back arch acts as a baffle-sheet, protecting the crown sheet and upper flues, and gives a more uniform distribution of heat throughout, resulting in less leaky flues and a saving in boiler repairs.

The arch can be used either with or without water-filled circulating arch tubes as supports.

Arches can readily be removed and reset, in whole or in part, without damage, to give access to flues when repairs are needed.

Fuel Economizers. Many devices have been employed whereby a portion of the heat may be extracted from the gases as they pass

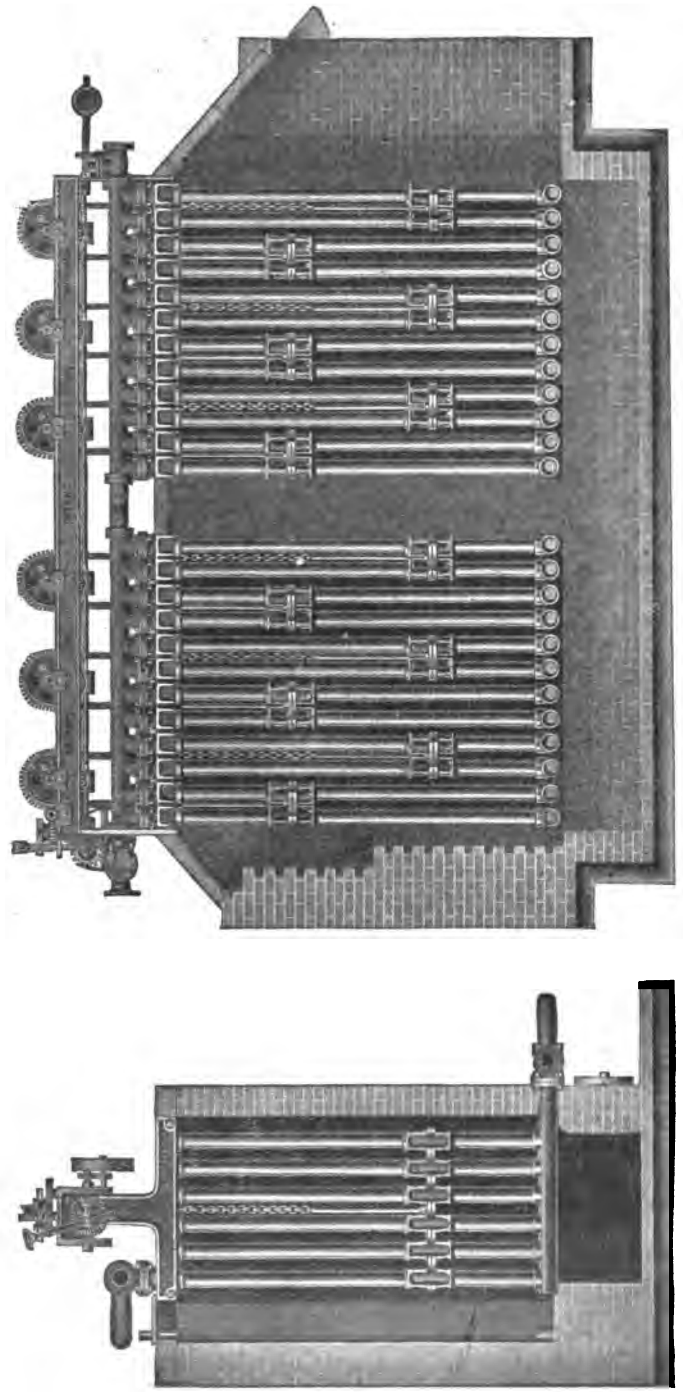
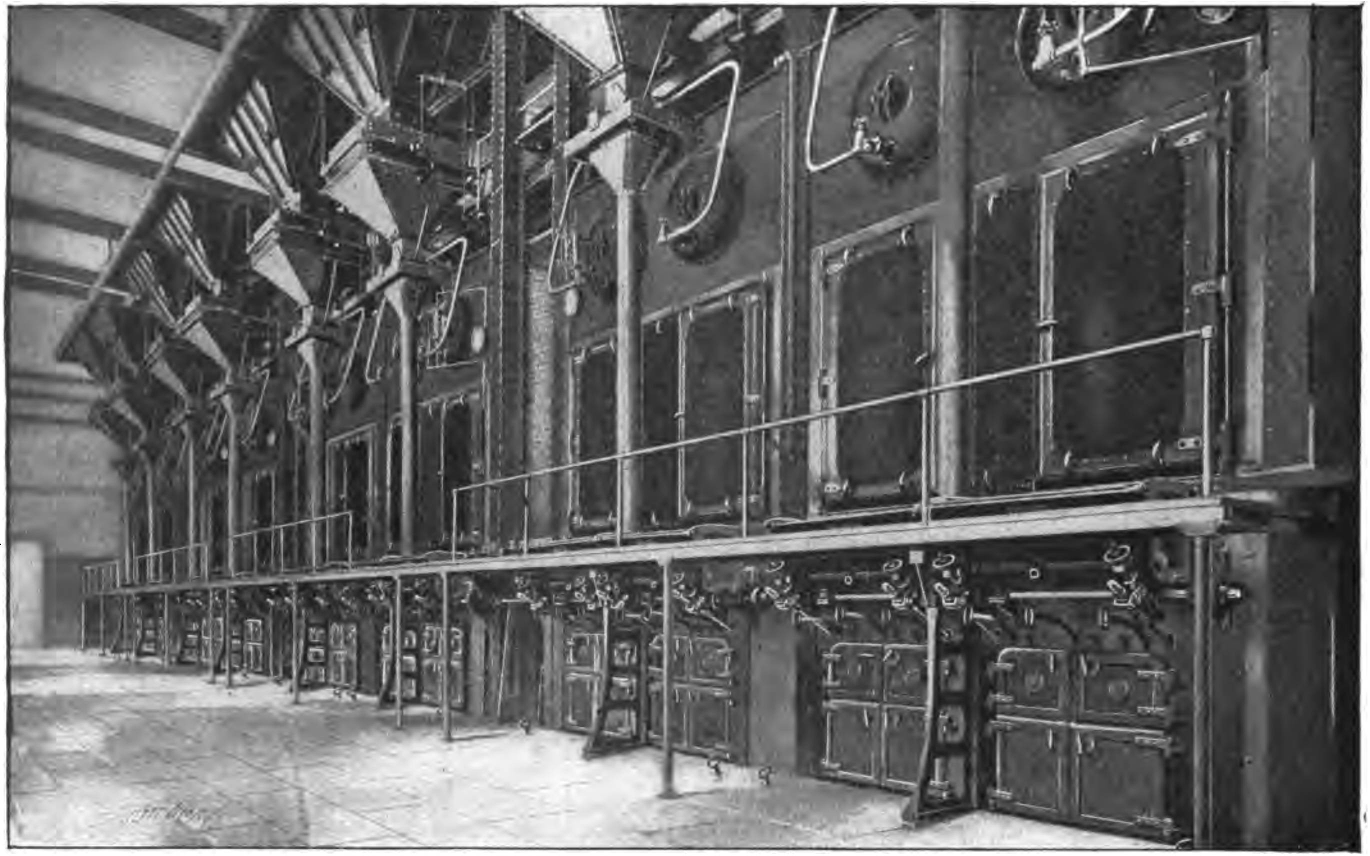


Fig. 16. Green Economizer.



VIEW OF 4000 H. P. OF BOILERS AND RONEY STOKERS
Installed in Plant of the Edison Illuminating Company, Boston, Mass.

from the boiler to the uptake. Most of these consist of a tubular arrangement through which the hot gases pass; but, as these are soon covered with a thick deposit of soot, they quickly become inoperative. The "Green" economizer (Fig. 16) solves this difficulty by means of small scrapers which work up and down between the tubes. These scrapers are operated by a small engine, and keep the tubes free from soot. The feed-water is pumped through these tubes on its way to the boiler, and is thoroughly heated. An economizer of this sort will extract 40 per cent or more of the heat from the waste gases; but by reducing the temperature of these gases, the draft is somewhat reduced, and either the chimney must be built higher, or a blower must be used.

Mechanical Stokers. The mechanical stoker, which feeds coal and tends fires by machinery, is coming more and more into general use. With a good mechanical stoker, one man can tend several furnaces with little labor. There are several different types, and in most of them the coal is fed into a hopper of such size that it need not be often filled. Some stokers work continuously; others, only when thrown into gear by the fireman. In the "Roney" stoker (Fig. 17), the grate-bars extend across the furnace, and form a series of steps down which the fuel moves. Each grate bar is hung on pivots at the ends, and is operated by a rocker-bar. This rocker-bar is driven by a small steam engine, with a slow, regular reciprocation which causes the grate-bars to tip so that the coal of its own weight slides from one grate-bar to the next. Coal from a hopper falls onto a horizontal plate, and is fed into the top of the grate by a *pusher*. The rapidity with which the fuel can be fed, is regulated by changing the stroke of the pusher and by governing the speed of the engine. Ashes

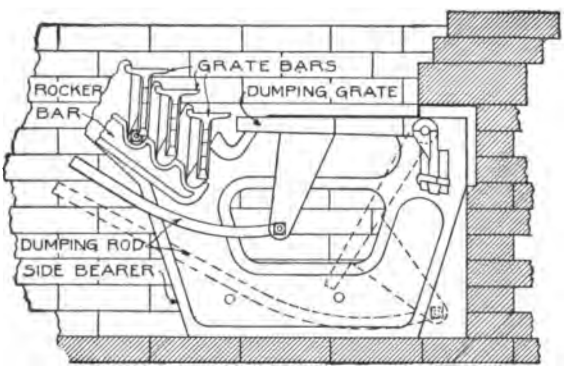


Fig. 17. Detail of "Roney" Mechanical Stoker.

and clinkers collect on the dumping-grate at the end of the grate-bars, whence they can be dumped into the ash-pit.

This type of grate is well adapted for smoke prevention, for the fresh fuel fed in at the top is rapidly coked, and the volatile gases are easily consumed. The rapidity of feed should be so regulated that no unburned fuel gets past the dump-grate. If the fire becomes too thin, there will be a loss of efficiency due to the excess of air which passes through the burning fuel. It is easy to detect the loss from too much fuel, but not so easy if there is too little fuel.

All mechanical stokers in which the movable parts are inside the furnaces, are likely to get out of order because of the heat and dirt.

Fusible Plugs. Fusible plugs are usually inserted in the top sheet or crown sheet of boilers, as a safeguard against collapse of the furnace crown should the water in any way be drawn out of the boiler while the fire is burning. These plugs consist of a core composed of an alloy of tin, lead, and bismuth, with a covering of brass or cast iron. The United States inspection law requires at least one fusible plug to be put in every marine boiler, with the exception of water-tube boilers, the plug to be made of a bronze casing filled with good-quality "Banca" tin from end to end. While this plug is kept at a comparatively low temperature by water on one side, the fire on the other side will not melt it; but when the water-level becomes low enough to leave one end of the plug uncovered, the alloy core of the plug, having a comparatively low melting point, will fuse, thus running out of its casing, relieving the pressure in the boiler, and allowing the excess of steam to extinguish the fire, which otherwise would be likely to destroy the crown sheet.

Fusible plugs are frequently unreliable. Sometimes they will blow out when there is no apparent cause, and sometimes remain intact when the plates have become overheated. If a coating of hard scale is allowed to accumulate over the plug, it may stand considerable pressure, even after the core has become melted. To provide against this, the plug should be replaced frequently. If allowed to remain in the boiler for any length of time, the composition of the alloy is likely to change, the plug thus becoming more or less unreliable.

Figs. 18 and 19 illustrate the ordinary plug. It should be so made that. when screwed into the crown sheet, it will project $1\frac{1}{2}$ or

2 inches above the plates, so that when the alloy melts there will be a sufficient depth of water over the crown sheet to prevent injury from heat.

Sometimes the core is covered with a thin copper cap, as shown

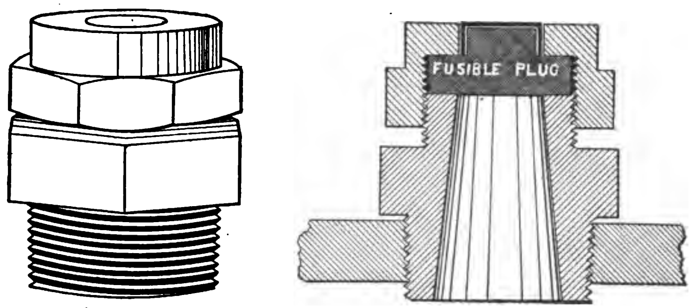


Fig. 18. Fusible Plug. At Right is Sectional View of Plug Attached to Crown Sheet of Boiler, to Give Automatic Warning in Case of Overheating of Plates.

in Fig. 18, which protects the alloy from contact with the water, thus preventing a chemical change and the formation of scale. It does not necessarily follow that a hole ½ inch or ¾ inch in diameter will

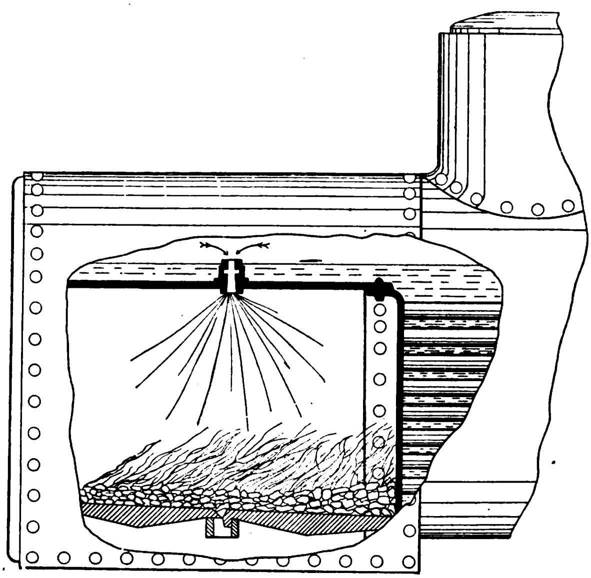


Fig. 19. Illustrating Action of Fusible Plug Attached to Crown Sheet.

liberate steam fast enough to prevent excess of pressure. If a small quantity of steam is introduced into the firebox, it may have the effect of brightening the fire and increasing the heat of combustion, owing to the formation of water gas as the steam mingles with the burning coal. The steam, moreover, might have the effect of inducing additional draft. If, however, the quantity of escaping steam and water is considerable, combustion will be retarded, and the fire will be partially extinguished. It will operate to warn the fireman of what has happened; and if the escape of steam is not too rapid, he may throw on wet ashes and deaden the fire.

NATURAL AND FORCED DRAFTS

The draft in a chimney is caused by the difference in weight between the volume of heated gases inside and the outside air. This being so, it is apparent that the taller the chimney, the greater this difference will be. The force or intensity of a draft is increased, and additional draft is induced, by the force of the wind as it whistles by

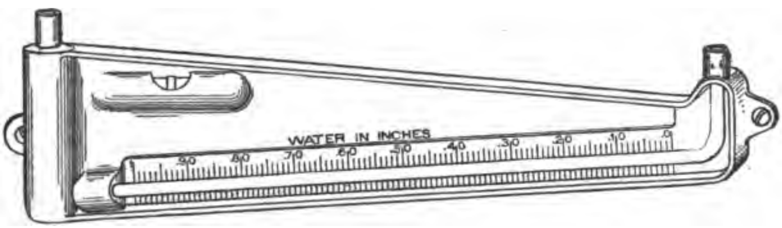


Fig. 20. "Eames Differential" Draft-Gauge.

the chimney top. The intensity may at any time be measured by a *draft-gauge*. The most satisfactory instrument of this sort is the "Eames Differential" draft-gauge, shown in Fig. 20. The tube is filled with a special non-drying, non-evaporating oil of known specific gravity. The incline and diameter of the tube are so proportioned that the readings are equivalent to inches of water, in which terms the draft is invariably measured.

Other things being equal, the rate of combustion depends upon the height of the chimney. A chimney 20 to 25 feet in height will cause a draft sufficient to burn about 8 lbs. of coal per square foot of grate area per hour. If the height is increased to about 100 feet, the rate of combustion will be increased to approximately 15 lbs. per square foot; and to burn 25 lbs., the chimney should be about 175 feet high. This is measured above the grate of the boiler. For good bituminous or anthracite coal, the chimney must be higher than for wood, if the same rate of combustion is desired. If the boiler has small or winding passages, the chimney must be higher to produce the same effective draft. High chimneys are costly; and it is frequently the practice to build two or three small chimneys in place of the big one, and to supplement them with some form of *forced draft.*

By means of forced draft, the rate of fuel combustion can be increased under favorable conditions to 100 lbs. of coal per square foot of grate surface per hour. This, of course, greatly increases the power of the plant, but is likely to injure the boiler, and is uneconomical under most conditions. There are three systems of forced draft in common use:

1. The *closed stoke-hold,* as used in marine work;
2. The *closed ash-pit;*
3. The *induced draft.*

Closed Stoke-Hold. One of the most common forms of forced draft, especially as used on warships, is obtained by closing the stoke-holds and blowing a fresh supply of air into the fire-room. This gives an exceedingly good ventilation and keeps the fire-room in good condition; but its chief objection is that when the furnace doors are opened there is a tremendous indraft of cold air, which tends to lower the efficiency of the boiler. If this system is employed, the bulkheads adjacent to the boiler-room must be provided with double doors, forming an air-lock between. By opening only one door at a time, the pressure in the fire-room is not lost. This system seems to possess but one distinct advantage, and that is coolness and therefore comfort for the firemen; but the disadvantage of the inrush of air to the furnaces when firing, is sufficient, in some cases, to make the system questionable.

Closed Ash-Pit. The essential features of forced draft by this method consist merely in closing the ash-pit tight, and blowing the air directly under the grate. When the fires are cleaned, the draft, of course, must be shut off; otherwise the flames will be blown out into the fire-room. The fire-room, under this system, is likely to be hotter than by the other method; but this system would seem to be the better from a mechanical point of view.

There are several patented devices in connection with the forced draft, of which the "Howden" and the "Ellis and Eaves" systems may be specially mentioned. It may be worth while to note that if fuel-oil is burned, any one of these systems of forced draft will work better than with coal, for the fire can be tended without opening the fire-doors.

Induced Draft. Perhaps the most common example of induced draft is to be found in the locomotive, where the exhaust steam is turned into the smokestack. The rush of this steam up the stack, by carrying a large volume of air with it, induces a tremendous draft. Induced draft may also be obtained in stationary and marine plants by placing a blower in the chimney or stack. In marine work, of course, induced draft by exhaust steam is out of the question. When a blower is placed in the smokestack, an economizer should be used, so that the gases may be cooled before they reach the blower. The draft obtained on locomotives is frequently equivalent to a column of five or six inches of water; while a forced draft of two inches is usually considered large, except for torpedo-boats, which may have as strong a draft as a locomotive has.

Howden System. The Howden system of forced draft with closed ash-pit has been used to a considerable extent in both mercantile and naval service. The air supplied to the ash-pit is first heated by passing through a heater in the uptake. Waste gases pass through tubes; and the air, passing among them before entering the furnace, is heated to a high temperature. A consumption of 60 lbs. of coal per square foot of grate is easily obtained with this system; and care must be taken that the fire is not forced too hard, as there is more danger of burning out the grate than if the air-supply is not heated.

Ellis and Eaves System. Heating the air does not necessitate its being forced into the closed ash-pit, for it is quite feasible to heat the air in connection with draft induced by an exhaust fan at the base of the funnel. Such is the Ellis and Eaves system. This system was first tried in the boiler shops at the works of the John Brown Company, in Sheffield, England, and was later adopted on many vessels. The Ellis and Eaves heater is fixed on top of the boilers, and is divided into two parts separated at the front by a smoke-box and at the back by a funnel. The hot gases, therefore—which pass outside the tubes—have to take a somewhat circuitous course; while the passage of the air to be heated, on the contrary, takes a direct course. The distribution of air to the ash-pit is similar to that of the Howden system.

The advantages of this system lie in the general convenience of the induced draft and the absence of jets of hot air shooting out into the boiler-room. The draft need not be shut off when stoking the fires, unless it is desired to prevent the inrush of air already referred to under the general discussion of "closed stoke-holds." The air in the fire-room being of a relatively higher temperature than would obtain with closed stoke-holds, and the quantity being much less, this objection has no great weight. With the Howden system it is necessary that the doors should be tight; otherwise hot air will be blown out into the fire-room. With this system a few leaks are of no consequence, and the fire-room will be somewhat cooler than with the Howden System. The objections to the Ellis and Eaves system are these inherent in any system of draft induced by a fan—that is to say, a poor efficiency of the fan working in heated gases, and lost work in drawing air through tortuous passages.

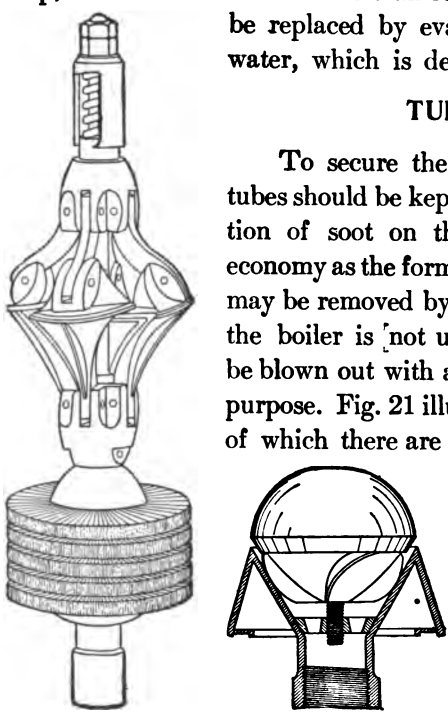
Steam Jets. Steam jets may be used for inducing a draft. They may be placed either in the smokestack, or below or above the grate; but in general they are not so economical as a fan used for the same purpose. In locomotives and fire-engines, where the exhaust steam is at high pressure, an intense draft may be induced by exhausting this up the smokestack. In both these cases, the saving of weight due to the use of a small boiler running at high tension, is of greater practical importance than the economy of fuel; and for such purposes this arrangement is entirely satisfactory.

A steam jet may be used directly in the furnace, either above or below the grate. The steam enters through a small pipe, and expands through a nozzle surrounded by an annular, funnel-shaped tube. The escape of steam from the inner nozzle draws in a large volume of air through the outer tube, and produces an intense draft. If steam is blown into the ash-pit in this manner, it forms a sort of producer gas by mingling with the incandescent fuel, and materially aids in the combustion of cheap and apparently worthless fuel. Almost as poor fuel can be successfully used with this arrangement as can be used in the grates of the down-draft furnaces. Such arrangements have given excellent satisfaction, and the production of smoke is materially lessened.

Some tests made in the French Navy some years ago, showed that, with the use of the steam jet above the grate, the coal consumption per square foot of grate area could readily be doubled; but this result would be attained at the expense of fuel economy; for, while with natural draft one pound of coal produced approximately eight pounds of steam which could be used by the engine, with a steam jet less than $6\frac{3}{4}$ pounds of steam per pound of coal was available for like purposes. The total evaporation per pound of fuel was approximately the same in each case, the difference being the quantity of steam used in the jet. If a steam jet is used on board ship, it consumes a considerable amount of fresh water, which must be replaced by evaporators, or by the use of salt water, which is decidedly objectionable.

TUBE-CLEANERS

To secure the best results from a boiler, the tubes should be kept thoroughly clean. The collection of soot on the tubes is as detrimental to economy as the formation of boiler scale. The soot may be removed by the insertion of brushes when the boiler is not under steam, or the tubes may be blown out with a steam jet designed for this purpose. Fig. 21 illustrates forms of tube-cleaners, of which there are numerous types on the market. The type shown at *B* is designed for use with a steam jet. In the case of oil-burning locomotives, the tubes are usually cleaned with the aid of a sand-blast.



A B

Fig. 21. Types of Tube-Cleaners.

TUBE-STOPPERS

It frequently happens, when tubular boilers are under pressure, that leaks occur in the tubes through pitting, defective welding, or the development of cracks. Formerly, when this occurred, the fire was drawn, and the ends of the tube plugged with hardwood bungs driven hard home or with iron plugs calked in. With high pressures, such procedure is impossible. Tube-stoppers used for high pressure are joined together by a tie-bar of some sort. They are usually wedge-shaped; and the tie-rod, passing through the stopper at one end, with a plug at the other end, can be screwed hard up.

The simplest form of stopper has to be inserted from the rear, and necessitates drawing the fire; but Fig. 22 illustrates a stopper which can be inserted without drawing the fire. At the end of the rod is hinged a folding bung, which can be passed through the tube and

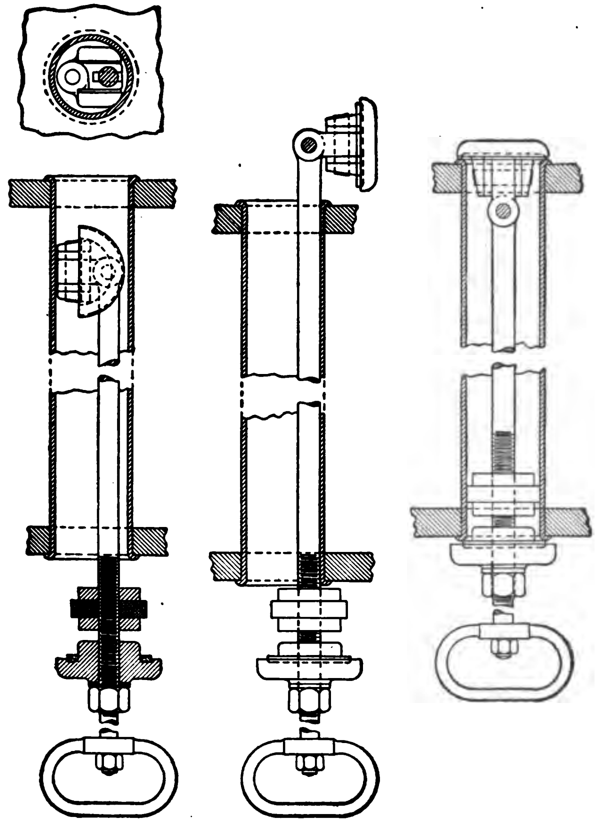


Fig. 22. Tube-Stopper Designed for Insertion without Drawing Fire.

which opens out in the combustion chamber before being pulled into position. At the smoke-box end of the boiler, an india-rubber washer, pressed between two pieces of metal, affords temporary protection while the plug is being put in position. The stopper can then be screwed up tightly with a handle provided for that purpose.

Fig. 23 illustrates another arrangement which can be inserted in the leaky tube without drawing the fire. The ends, being in the form of stuffing glands, press an asbestos packing hard against the side of the tube.

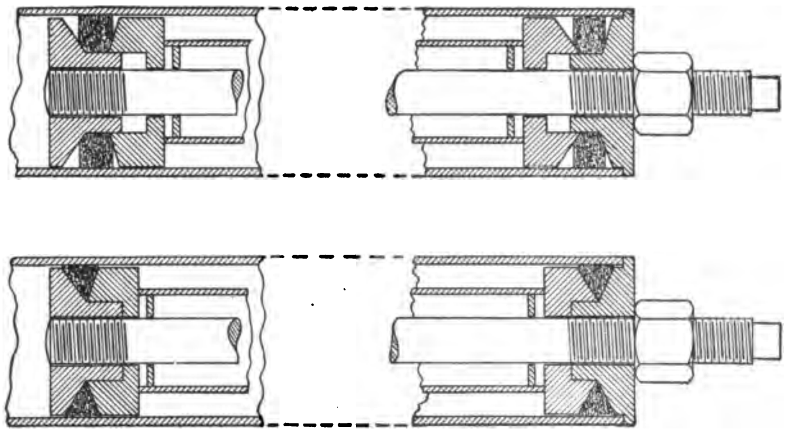


Fig. 23. Another Type of Tube-Stopper Used without Drawing Fire. As the Parts are Screwed Up, the Asbestos Packing is Driven Hard against Side of Tube.

MANHOLES AND HANDHOLES

A *manhole* allows access to the boiler for cleaning and repairs. It is usually elliptical in form and large enough to admit a man. About 16 inches for the major axis, and 12 for the minor axis, is a good size. The manhole is closed by a plate or cover made of cast or wrought iron. This plate is held to the seat by a yoke or yokes, and bolts. Fig. 24 shows one form, *Y* being the yoke, *L* the cover, and *N* the bolt. The joint between the cover and the shell is made steam tight by packing.

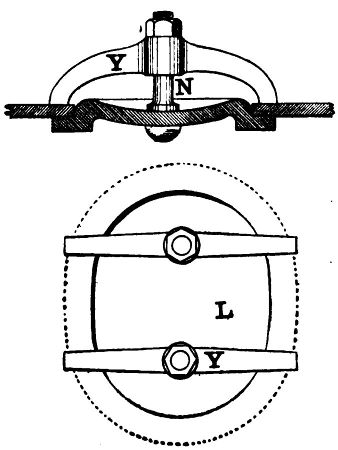
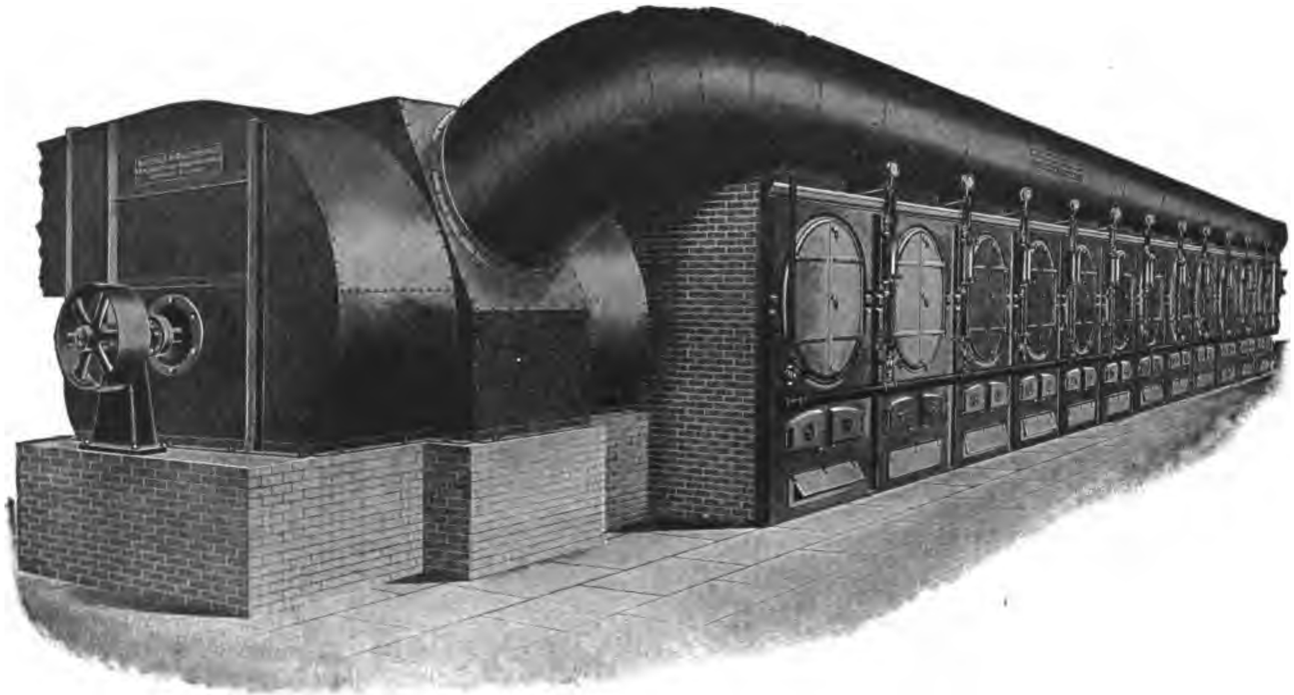


Fig. 24. Elevation and Plan of Manhole Cover.

The *strength* of the boiler should always remain unimpaired; so, whenever a large hole is cut in the plate, the edge should be strengthened, for the tension is concentrated there, and the plates are, moreover, likely to become weak by corrosion. The strain put upon the plate by screwing up the cover, if no packing is used, is considerable, especially if a piece of scale gets between the faces and the joint is then made tight.



BOILERS EQUIPPED WITH DUPLEX THREE-QUARTER HOUSING FANS.
Induced Draft Plant at Watkins Salt Company.
Buffalo Forge Company.

Fig. 25 shows the section of a strong and simple manhole. The edge of the plate is strengthened by a broad ring of steel, which is flanged and riveted to the shell, its edge forming the seat. The cover as shown in the figure is shaped for strength. The edge of the ring which forms the seat, and the cover, are machined to make a tight joint without packing. The strengthening ring should be at least $\frac{5}{8}$ inch thick and 4 inches wide, that the rivet-holes may not be too near the edge.

Handholes and *mudholes* are more commonly placed in boilers, which are so constructed that a man cannot enter—in a vertical boiler, for example. They are used to some extent in other boilers; in horizontal return-tube boilers there is usually a handhole in each end,

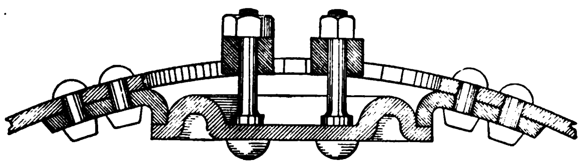


Fig. 25. Section of a Strong but Simple Type of Manhole.

near the bottom. Handholes are very convenient to admit hose for washing out the boiler, also for removing scale and sediment. Handholes are similar to manholes in construction, but require only one yoke and one bolt to keep them in place. Mudholes should be provided in order that the sediment and detached scale can be removed without lifting the accumulated mass to the top manhole. Mudholes and handholes greatly facilitate cleaning the fire-box water-leg of locomotive and small vertical boilers.

STEAM AND VACUUM GAUGES

The steam pressure in the boiler is measured in *pounds per square inch.* When we say the boiler is working or steaming at 80 pounds' pressure, we mean that the gauge pressure is 80 pounds; that is, the pressure in the boiler is 80 pounds above *atmospheric pressure.* It could be measured by a water or mercury column; but, as these would need to be very high to measure the pressures used at the present day, they are not practicable, and so a spring-pressure gauge is used instead.

The dial gauge, now used almost universally, was invented by M. Bourdon. It is designed in accordance with the principle that a flattened, curved tube closed at one end tends to become straight when subjected to internal pressure.

The tube, which is usually oval in section, is bent into the arc of a circle as shown in Fig. 26. One end is *fixed,* and is in communication with the boiler. The other is *closed* and free to move. By means of levers, a curved rack, and a pinion, the motion of the free end is *multiplied* and *indicated* by a needle, which is attached to the pinion. The needle moves over a dial which is graduated to agree with a mercury column, or with a standard gauge. The back-lash of the levers is taken up by a hair spring. Fig. 27 shows the interior and face of a Bourdon steam gauge manufactured by the American Steam Gauge Company.

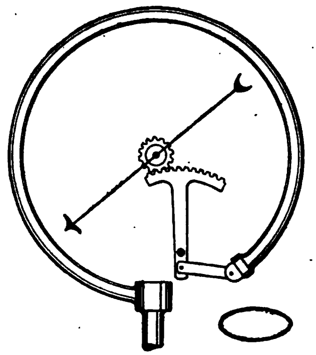


Fig. 26. Steam-Filled Curved Tube Indicating Pressure in Bourdon Steam Gauge.

Fig. 28 shows the exterior and interior of a steam gauge with a light tube for low pressures; the face of the dial is graduated corresponding to the mercury column. The only difference between this gauge and the *vacuum gauge,* is that in the latter the curved tube is

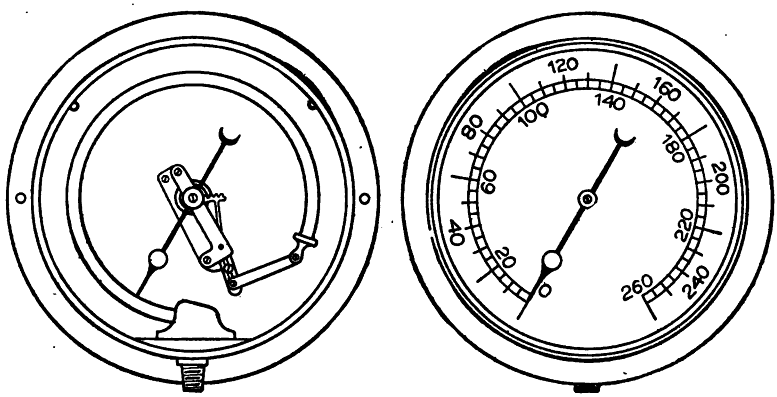


Fig. 27. Interior Mechanism, and Dial, of "Lane" Type of Steam Gauge.

turned in the opposite direction so that the needle will move clockwise with a *decrease* of pressure.

On account of the jarring, the gauge for locomotives must be very strong. To prevent excessive vibration of the needle, two short, stiffer springs are used, as shown in Fig. 29.

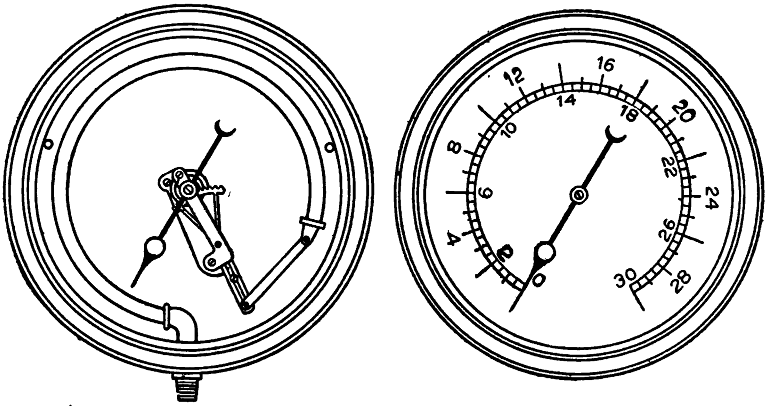


Fig. 28. Interior Mechanism, and Dial, of Low-Pressure Steam Gauge.

Sometimes two pressure gauges are fitted to a boiler, one indicating the working pressure, and the other graduated to about twice the working pressure. The latter is useful in testing the boiler under water pressure, and also serves as a check on the other. The pipe which connects the pressure gauge to the boiler should have bends in it near the gauge. These bends—or, better, a *coil pipe*, as shown in Fig. 30—

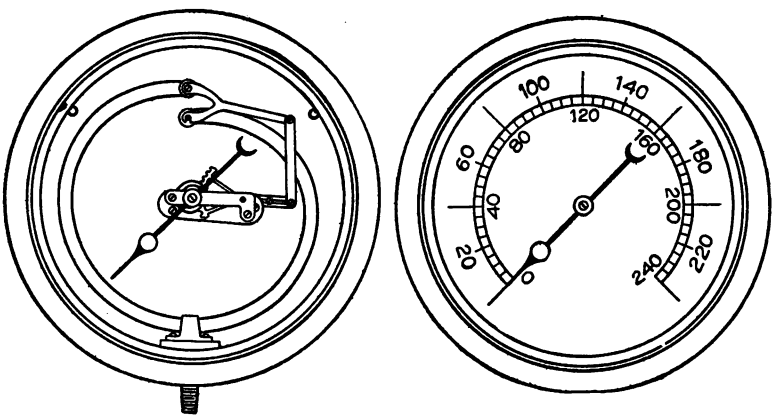


Fig. 29. Steam Gauge for Use on Locomotives. Excessive Vibration of Needle Prevented by Use of Two Short, Stiff Springs.

are filled with water, which transmits pressure and keeps the spring at a nearly constant low temperature. Gauges should be placed where the water in the coiled pipe will not freeze; also, the gauge should not be exposed to strong heat. In order that the gauge may be

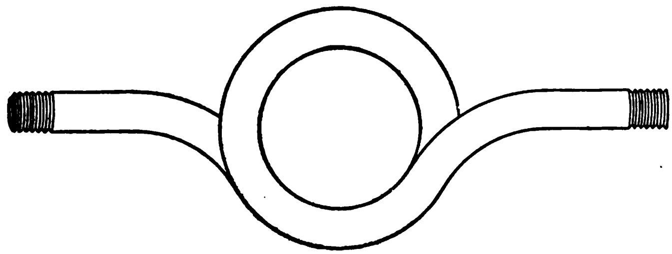


Fig. 30. Water-Filled Coil Pipe for Connection to Steam Gauge. The Water Transmits Pressure and Regulates Temperature.

removed from the boiler for examination, repairs, or calibration, when the boiler is under pressure, the connection should be provided with stop-cocks.

In a battery of boilers, *each should have its pressure gauge,* which should be connected *directly* to the boiler, *not* to the steam pipe.

WATER GAUGES

It is of great importance that the level of the water in the boiler can easily be ascertained at all times. Should the level be too low, there is danger of overheating the furnace plates or tubes. If it is too high, there is likely to be an undue amount of priming. The water-level is usually indicated by gauge-cocks or try-cocks or water gauge-glasses. Sometimes a float is provided, which is connected to a small whistle, and if the water-level falls below a

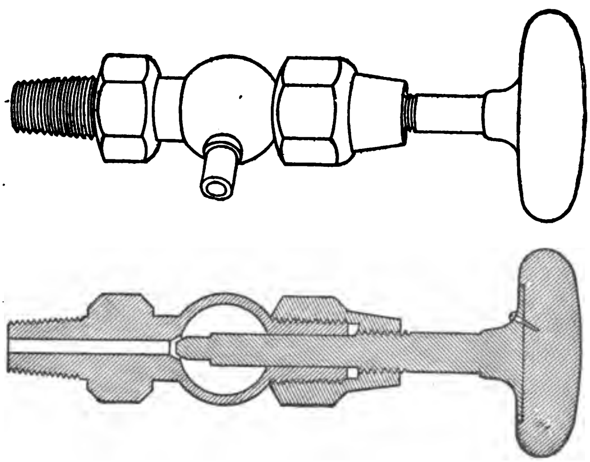


Fig. 31. Ordinary Form of Try-Cock for Determining Water-Level in Boiler.

certain point, an alarm is sounded. Such a device can readily be used in conjunction with the ordinary water-gauge.

Try-Cocks. Try-cocks are very generally used. They are of widely different forms, and may be either like the general type shown in Fig. 31, which is the ordinary locomotive form, constructed in two parts so that they can be separated for the purpose of repacking without detachment from the boiler; or they may be of the lever type shown in Fig. 32. There are usually three cocks, one at the highest desired water-level, one at the lowest, and one midway. More cocks may, of course, be used if desired. The water-level can be determined by opening the cocks in succession and observing whether dry steam or hot water flows out. If the boiler is encased in brickwork, as is customary for externally-fired boilers, the gauge-cocks are placed outside the brickwork, and are connected to the boiler by nipples of the proper length.

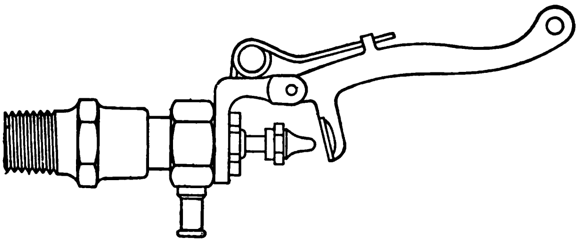


Fig. 32. Try-Cock Operated by Means of Lever.

Gauge-Glasses. In order that the fireman may know the water-level *without* trying the cocks, a water gauge-glass is used. It consists of a strong glass tube about one foot in length, having the ends connected to the boiler by suitable fittings.

As both ends of the tube are in communication with the boiler, the water-level in the glass will be the same as in the boiler, and is *always in sight.* Fig. 33 shows a good form of gauge-

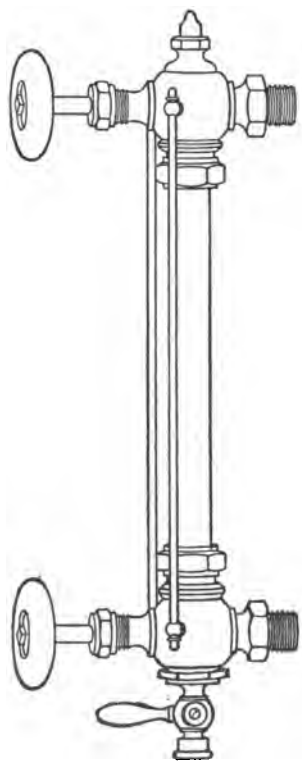


Fig. 33. A Good Type of Water Gauge-Glass.

glass. The glass is protected by rods which are parallel to it. As the glass frequently needs cleaning, repacking, or renewing, cocks are provided for shutting off communication with the boiler. A drain-cock is also placed at the lower end to empty the glass when the attendant wishes to ascertain whether the glass is working properly or not. The drain-cock is often provided with a drain-pipe. The steam and water passages should be at least one half-inch in internal diameter.

The glass is likely to break because of accident or of changes in temperature. To prevent serious injury to the fireman and loss of water as a result of the breaking of the gauge-glass, *automatic valves* may be placed in the passages. In Fig. 34 the ball-valve is shown in detail. If the glass breaks, the pressure of the steam drives the ball outward, filling the conical passage. When a new glass is put in, the balls are forced back by slowly screwing in the stems. This, like other safety devices, is very likely not to work when it should.

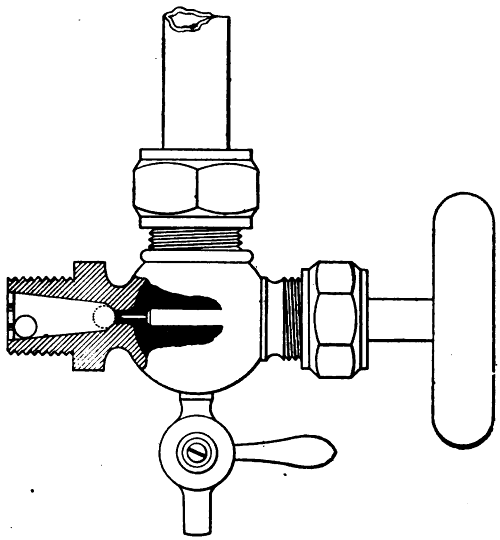


Fig. 34. Automatically Acting Ball-Valve to Prevent Injury to Workmen and Loss of Water on Breaking of Gauge-Glass.

In boilers where the steam space is small, as in locomotives, the allowable variation of water-level is slight; but the greater care with which the glass is watched makes up for the small margin of safety. If dirty water is used, or if the water foams, the level in the glass will be unsteady and unreliable, since dirt clogs the passages, unless they are large, and the foaming causes a fluctuation of the water-level. A small pipe connecting with the steam space where no ebullition occurs, will insure a steadier water-level. If the steam and water connections are long, the pipes should be made large.

The chief objection to the gauge-glass—namely, its breaking—may be to some extent overcome by attaching the gauge-glass to a *gauge-column*, which is usually made of brass and stands quite clear

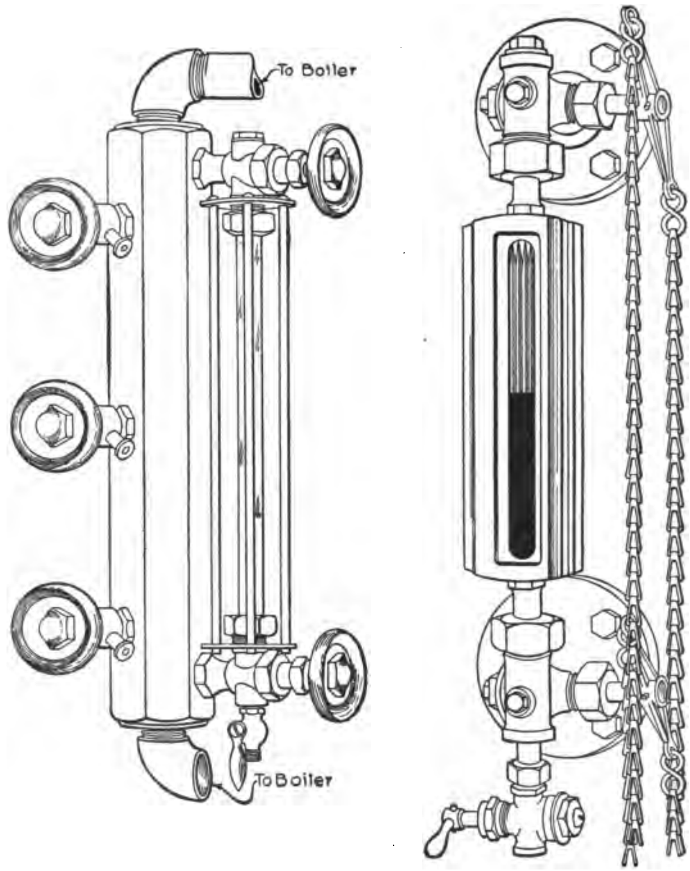


Fig. 35. Ordinary Water Gauge-Glass Supplemented (at right) by "Klinger Patent" Gauge-Glass.

of the boiler itself. In such an arrangement as this, the temperature in the gauge-glass cannot vary so widely as if it were attached directly to the boiler. The "Klinger Patent" water gauge-glass is not easily broken, and possesses many advantages over the common glass. Fig. 35 illustrates both these devices.

The water gauge is not absolutely reliable, for the water in the gauge, being cooler than that in the boiler, may not indicate the true level, and the small passages leading to it may become choked with sediment. If the gauge-glass is frequently blown out by the engineer and kept clean, this difficulty will be reduced to a minimum.

VALVES

Of all boiler accessories, perhaps the most important are the *cocks* and *valves* by means of which the flow of steam or water may be shut off completely or partially. The valve operates by moving a disc across the pipe in a transverse direction, or by bringing a cap

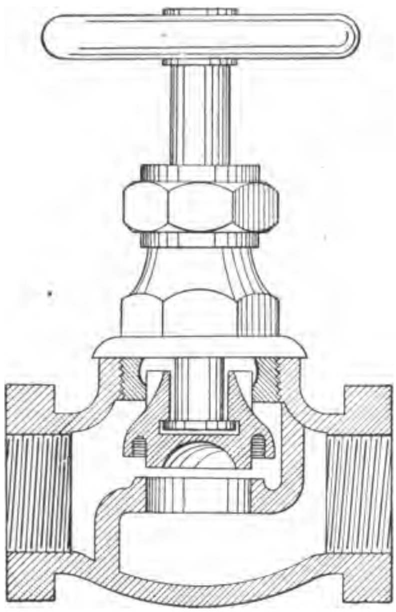


Fig. 36. Ordinary "Competition" Type of Globe Valve.

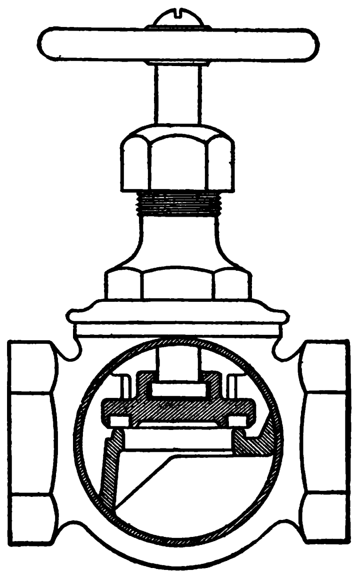


Fig. 37. Globe Valve with Detachable Cap and Removable Interior Disc of Comparatively Soft Material to Insure Tightness.

tight upon the seat in a fore-and-aft direction. A cock consists of a block inserted in the passageway, with an opening cut through in one direction. When the handle of the cock is in line of the pipe, the opening allows the steam to pass through; but if turned crosswise, the opening is closed.

The Globe Valve. The valve shown in Fig. 36 gets its name from the globular shape of the casing which encloses the valve. Extending across this whole casing is a substantial diaphragm, the central portion of which is in a plane parallel with the length of the pipe. The opening is cut in this portion, horizontal in the figure, through which steam or other fluid may pass when the valve is opened. When the valve is closed, a cap is forced down to close its opening. The rim around the opening is known as the *valve-seat.* The valve-cap is operated by a spindle, which passes through the bonnet of the valve and is mounted at the upper end by a small wheel or handle. To prevent the escape of steam around this spindle, a stuffing-box is provided. The valve-cap may or may not rotate as the spindle turns; usually it does not. The valve shown in Fig. 36 is the ordinary globe valve known to the trade as the "Competition" valve. It is the cheapest valve of the type, and is not satisfactory where absolutely tight work is required. If the cap becomes scored, the valve will leak and is then worthless.

A valve shown in Fig. 37 has a detachable valve-cap; and instead of relying for tightness upon the valve and seat coming together, metal to metal, a removable disc is provided, which being softer than the metal valve-seat, easily takes up the wear, and the valve not only can be closed tighter, but if anything happens so that the tightness of the valve is impaired, the valve-cap can be replaced by another at a trifling expense. In the cheaper valve, when the cap is scored, the valve is worthless. The valve-seat sometimes has a slight bevel, the valve-cap being shaped like the frustum of a cone.

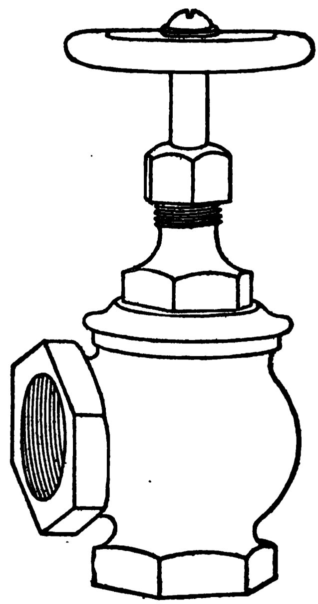


Fig. 38. Angle Valve of Ordinary Globe Pattern.

It is impossible to close a valve tightly if the slightest particle of scale or grit gets between the disc and the seat. If this happens, the valve-seat is likely to become scored so that it does not hold tight; but it may be reground, and if the valve disc itself is damaged, it can readily be replaced.

Angle Valves. An angle valve, shown in Fig. 38, is constructed in a similar manner to the ordinary globe valve, and is sometimes used in place of the straightway valve and an elbow. Both these styles of valve should be so placed in the steam pipe that the entering steam comes beneath the valve-seat. If this is done, the valve-stem may easily be repacked simply by closing the valve. If the steam enters in the opposite direction, a leaky valve-stem cannot be packed, as loosening the stuffing-box would permit the escape of the steam.

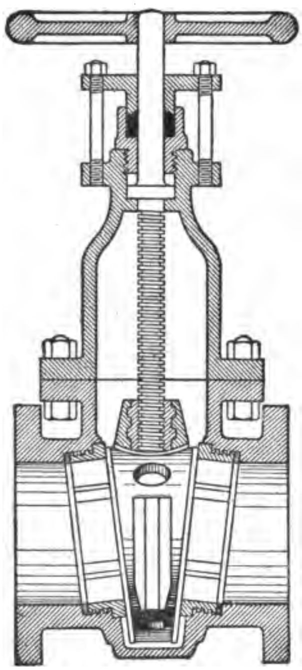
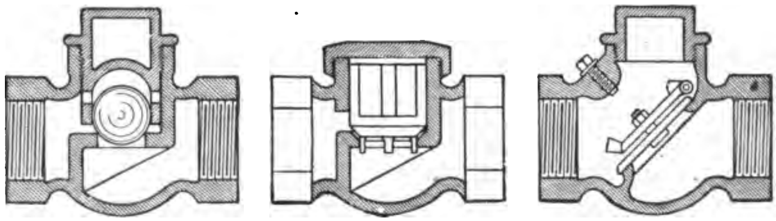


Fig. 39. "Chapman" Gate Valve with Wedge-Shaped Sides.

The Gate Valve. The *gate* or *straightway* valve gives a straight passage through the pipe, and, when open, offers very little resistance to flow. The globe valve, of course, offers much resistance, because the fluid has to change its direction of flow completely.

There are two forms of gate valve—one with wedge-shaped sides, and the other having the valve sides parallel. Fig. 39 shows a "Chapman" valve with wedge-shaped sides. A collar holds the valve spindle at a fixed point; and to open or close, the valve is drawn up or lowered by turning the spindle. When the gate reaches the bottom of the pipe, a wedge on the lower end of the spindle causes the sides to move laterally, with sufficient force to bring a strong pressure against the valve-seat. For heavy work, these valves are made with a rising spindle instead of a stationary one. This possesses the distinct advantage of indicating at a glance whether they are opened or closed, while one cannot tell by looking at the ordinary gate valve whether it is open or not.

Check-Valves. When it is necessary that the flow should always take place in the same direction, as in the feed-pipe of a boiler, *check-valves* are used. There are several forms shown in Fig. 40, one of which has a similar pattern to a globe valve, with a ball or flat valve, the seat being parallel to the direction of flow. The valve is held in place by its own weight, and by the pressure of the fluid in case of a reverse flow. In the *swinging* check-valve, the seat is at an angle of about 45 degrees to the direction of flow. It is fitted somewhat loosely where it is fastened to the swinging arm, so that it may properly seat itself. This form is usually preferred, as it offers less resistance to flow and there is less chance for impurities to lodge on the valve-seat. When a check-valve is used in the boiler-feed pipe,



A B C

Fig. 40. Types of Check-Valves. *A*-Ball-Valve; *B*-Flat Valve; *C*-Swinging Check-Valve.

there should be a *stop-valve* between it and the boiler, which can be shut in case the check-valve should get out of order.

Materials. For pressures under 200 lbs. per square inch, cast iron may be used for the body of the valve; but, for economy, it should be used only when the pressure is over 130 lbs. For heavy work it is frequently necessary to have a massive valve that cannot easily be broken. In such a case a cast-iron body is the most suitable thing. The valve-seat, valves, spindles, stuffing-box, glands, and nuts are usually made of gun-metal or brass. For very high pressures, especially on steam mains, cast steel is generally used, with gun-metal fittings similar to those enumerated for the cast-iron valves.

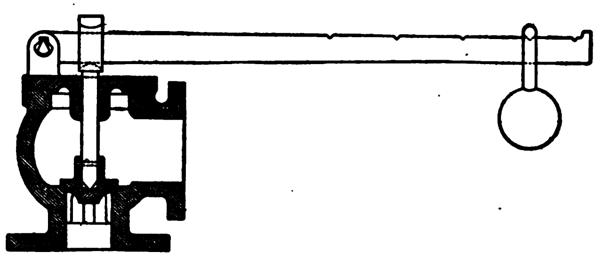


Fig. 41. Common Type of Lever Safety-Valve.

Safety-Valves. Safety-valves are used for reducing the pressure in the boiler when it exceeds a certain limit, and to give warning of high pressure. There are several different types, but the essential features are a valve opening upward, held on its seat by a weight or spring. When the pressure in the boiler exerts a force greater than that holding down the valve, the valve will open automatically.

The *lever safety-valve* shown in Fig. 41 is the most common type for stationary work, especially for small boilers. The valve is held in place by a weight at the end of a lever. The force required to lift the valve is governed by the location of the weight on the lever-arm. The body of the valve is usually made of cast iron, the seat being of brass. An opening on the side of the valve may be connected with the feed-water heater or drain, if the escape of steam into the air is undesirable. If the valve becomes leaky, it should be reground; but no attempt should be made to make it tight by increasing or moving the weight on the lever.

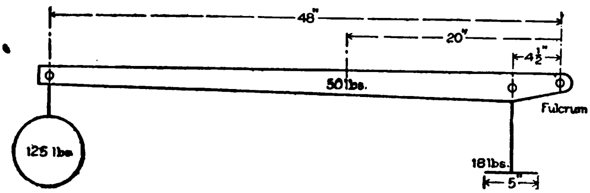


Fig. 42. Diagram for Safety-Valve Calculations.

The amount of necessary weight on the lever, and its distance from the fulcrum, can be determined in the usual manner of computing leverage forces and moments, remembering that weight times weight-arm is equal to power times power-arm. In such a valve as this, *power* is the steam pressure, and the *power-arm* is the distance of the center of the valve from the fulcrum. There are four weights acting downward—the ball, the lever-arm, the valve, and the spindle—and in the process of computation the weight and leverage of each must be taken into account.

Suppose, for example, that we have a lever safety-valve such as is illustrated in outline in Fig. 42, and that we know the following conditions: the ball weighs 125 lbs., and is suspended at the end of the lever 48 inches from the fulcrum; the valve and valve spindle together weigh 18 lbs., and are 4½ inches from the fulcrum; the lever-arm itself weighs 50 lbs. If the valve-seat is 5 inches in diameter, at what pressure will the valve blow off, ignoring the friction of the stuffing-box and fulcrum pivot?

The center of gravity of the lever-arm must be determined from the drawing (Fig. 42), and this is found to be 20 inches from the fulcrum. The leverage of the weights acting downwards is then as follows:

Ball	125×48	= 6,000
Lever	50×20	= 1,000
Valve and Stem	$18 \times 4\frac{1}{2}$	= 81
Total moment		= 7,081 inch-pounds.

Now, if the valve-seat diameter is 5 inches, the area of the valve will be $\frac{\pi D^2}{4} = \frac{3.1416 \times 25}{4} = 19.63$ sq. in. The total moment to be overcome is 7,081 inch-pounds, and its distance from the fulcrum is $4\frac{1}{2}$ inches. Therefore the necessary upward pressure on the valve will be $\frac{7{,}081}{4\frac{1}{2}} = 1{,}573.5$ lbs. If the area of the valve is 19.63 sq. in., then the necessary pressure in pounds per square inch would be $\frac{1{,}573.5}{19.63} = 80$ lbs., approximately. That is, this safety-valve would blow off when the boiler pressure reached 80 lbs. per square inch.

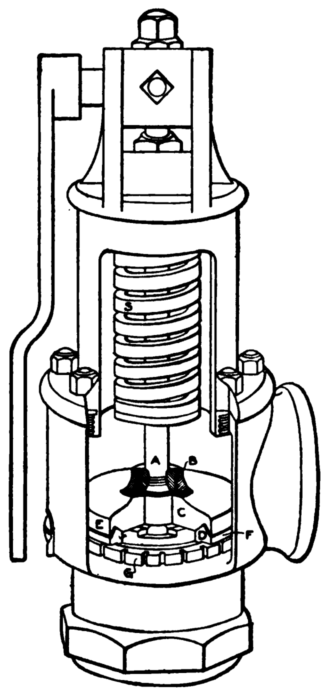


Fig. 43. "Crosby" Pop Safety-Valve for Stationary Boilers.

If it is desired to design a valve that will blow off at known pressure, the same principles will apply, but the computations will be figured in the reverse order. The area of the valve, times the boiler pressure, would give the total lifting force; and this, multiplied by its leverage, would give the lifting moment, which would be resisted by the downward moment of the combined weights of valve, valve-stem, lever, and ball. If the moments of the lever, valve, and valve-stem were known, the rest, of course, would be made up by the ball. If the length of the lever-arm were known, then the weight of the ball would be varied to correspond; and, conversely, if the weight of the ball were fixed, the length of the lever must be made to correspond.

The lever safety-valve has several defects. It does not close promptly when the pressure is reduced; and it is likely to leak after it is closed, and may readily be overloaded, or even wedged on its seat. It is essential that a safety-valve should be automatic, certain in its action, and prompt in opening and closing at the required pressure. It must be one that can be relied upon under all circumstances.

The *pop safety-valve* fulfils the above requirements better than those of the lever type. Pop valves open when the steam pressure is sufficient to overcome the tension of the spring. Fig. 43 shows a "Crosby" pop safety-valve for stationary service. The valve *C* is connected by the flange *B* to the central spindle *A*, and is held down on its seat by the pressure of the spring *S*. The valve *C* is provided with wing guides and an annular lip *E*. The guides fit smoothly into the seating *D*, upon which the valve rests. The seats of the valve have an angle of 45 degrees. The under face of the lip *E*, together with the seating, forms a small chamber through which all the steam must pass to the open air. A number of small holes drilled vertically through the flange *F*, connect with the chamber and allow part of the steam to escape. The action of the valve is regulated by the screw ring *G*, which allows more or less steam to escape through the holes in the flange *F*. Raising the screw diminishes, and lowering it increases, the area of the holes. If the loss of steam is too great when the valve blows, turn the screw ring down.

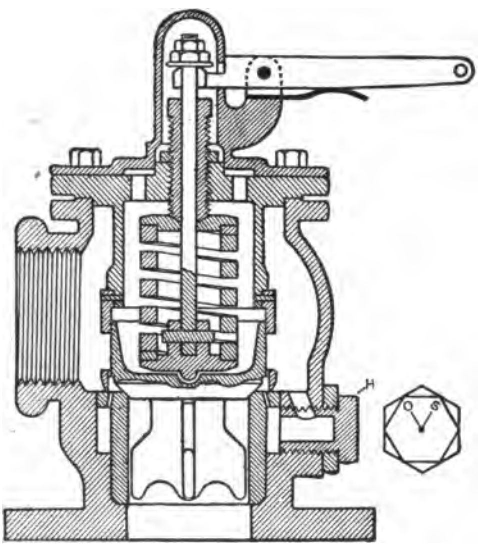


Fig. 44. "Ashton" Valve with Pop Regulator for Stationary Boilers.

Safety-valves *should be connected directly to the boiler* without any pipe or elbow. They should be tried every day by means of the lever.

The valve shown in Fig. 44 for stationary boilers, is made by the Ashton Valve Company. The general principles are those of all pop safety-valves. The valve-seat is made of composition or nickel, and with a bevel of 45 degrees, as is the United States Government standard. The pop chamber is surrounded by a knife-edge lip, which wears down in proportion with the seat, thus keeping the outlet of the same relative proportions, giving a constant amount of pop.

The amount of pop—that is, the difference of pressure between the opening and the closing of the valve—is regulated from the out-

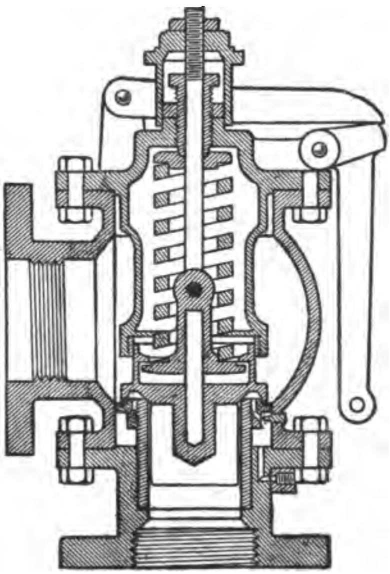


Fig. 45. "Star Marine" Pop Safety-Valve, with Cam Lever.

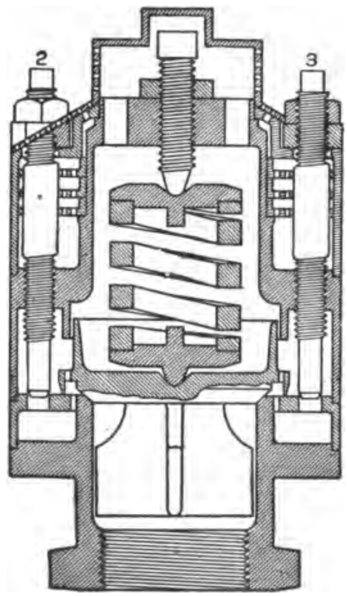


Fig. 46. "Ashton" Safety-Valve for Locomotive Boilers, with Pop Regulators on Each Side, and Top Muffler.

side by means of the screw-plug *pop regulator* shown at H in Fig. 44. If more pop is desired, turn the regulator so that S will be more nearly perpendicular. To lessen pop, make O more nearly perpendicular. The springs are made of Jessop's best steel.

The inlet and outlet are both on the same casting, so that the valve may be taken apart to be cleaned or repaired, without disturbing the boiler connection. It has a lock-up attachment, so that the regulating parts cannot be tampered with, either by accident or by design. The spring is encased, thus protecting it from the steam.

The "Star Marine" pop safety-valve is shown in Fig. 45. It has a bevel seat, and is provided with a cam lever by which it may be raised from its seat when there is no steam pressure. The outlet of the valve, if desired, may be piped to the supply tank or to any other point.

Safety-valves for *locomotive boilers* must be made of heavy material to stand the severe usage. They should be so constructed that they will not cock or tilt. The "Ashton" valve shown in Fig. 46 is con-

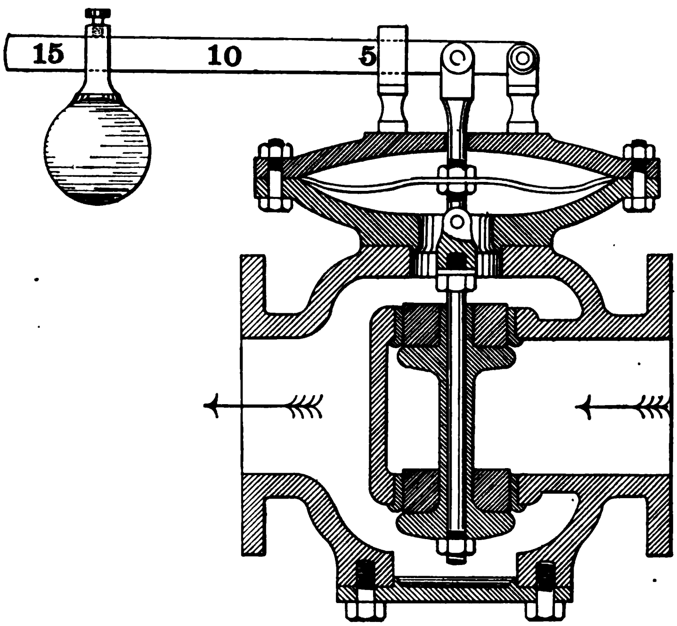
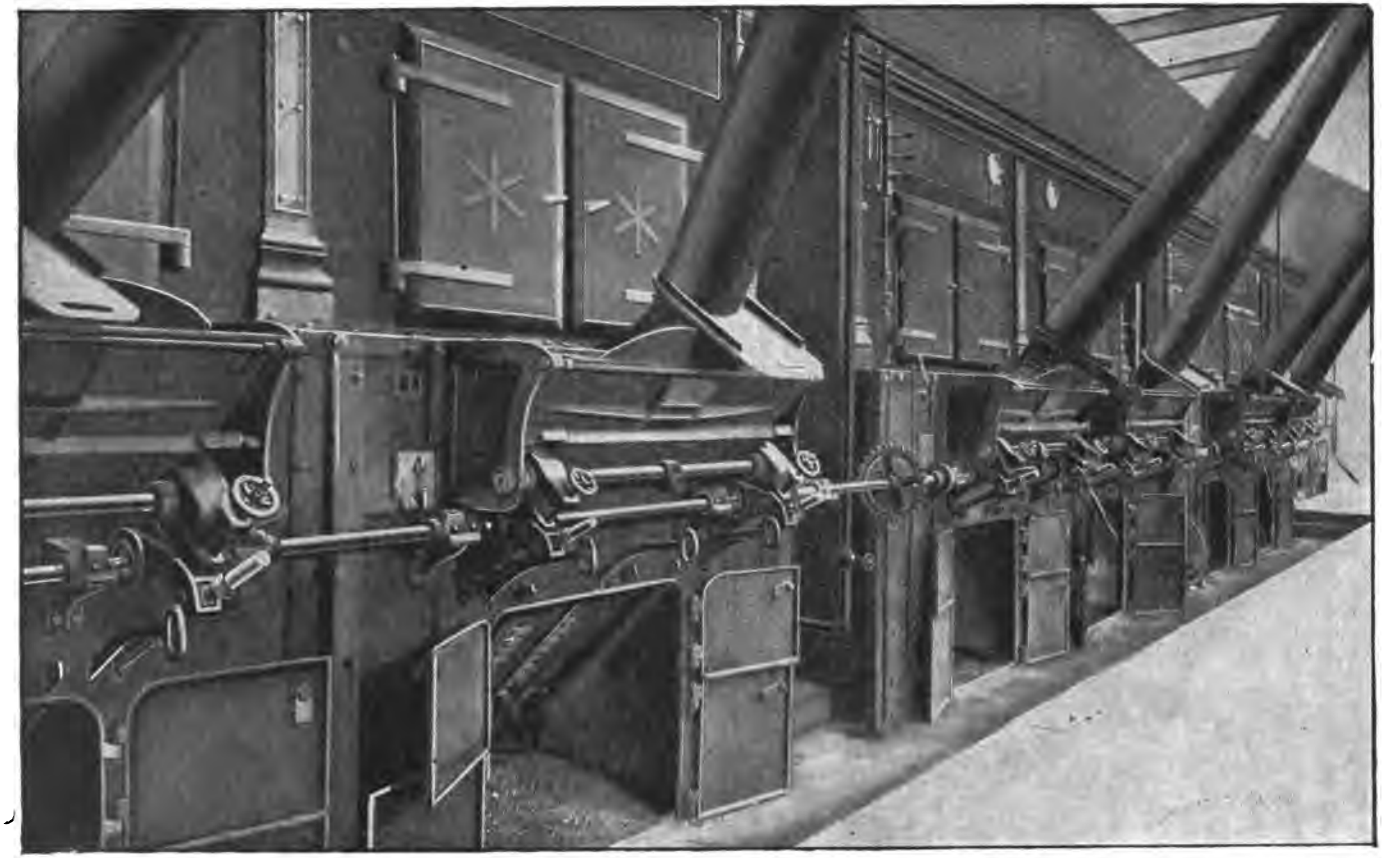


Fig. 47. "Holt" Reducing Valve with Diaphragm Regulating Pressure.

structed so that the amount of pop can be regulated by merely turning the two posts marked 2 and 3 to the right or left. The noise of the steam escaping from the ordinary safety-valve is disagreeable, and in some States the law requires the use of the *muffler safety-valve.* The Ashton valve shown in Fig. 46 has a top muffler.

Reducing Valves. Sometimes steam is desired at a lower pressure than that of the boiler. For instance, a small low-pressure engine may be run by steam taken from the same boiler that supplies a higher-pressure engine. This reduction is accomplished by throttling the steam by means of *reducing valves.* These are arranged to be



PARTIAL VIEW OF A PLANT OF 2700 H. P. OF RONEY STOKERS
Joseph Schlitz Brewing Company, Milwaukee, Wis.

operated automatically so that the pressure can be reduced and a constant pressure in the steam pipes maintained. There are several forms in general use.

In the "Holt" valve, Fig. 47, the low-pressure steam acts on the lower side of the diaphragm; and the weight, which may be set so as to cause the desired pressure, acts on the other. The movement of this diaphragm causes a balanced valve to move to or from its seat. The valve opens until the steam pressure equals the weight above. The pressure in the main steam pipe does not affect the movement of the valve. It depends only upon the pressure on the two sides of the diaphragm.

Another form, the "Mason," is shown in Fig. 48. A spring, which may have its tension altered by a key, takes the place of the lever and weight in the Holt valve. When the pressure in the low-pressure system has risen to the required point, which is determined by the spring, the valve closes, and no more steam is admitted until the pressure falls sufficiently to open the valve again.

In another form, a piston acted on by the low-pressure steam regulates the opening of a balanced valve, and this maintains a constant steam pressure.

In the "Foster" reducing valve, the valve is held open by the spring and levers, until the steam pressure at exit presses on the diaphragm sufficiently to close the valve. The valve is held open so as to admit just the proper amount of steam to maintain the required pressure.

When a reducing valve is used, a stop-valve should be put in to prevent flow when steam is not in use.

BLOW-OUT APPARATUS

Boiler feed-water, if taken from rivers or ponds, is likely to contain vegetable matter as well as solid materials. The vegetable matter will usually float to the surface, while the solids will collect at the bottom. To keep the boiler clear of such sediment, it is necessary to provide two *blow-outs*—a *surface* blow-out, to take care of what rises to the top; and a *bottom* blow-out, to take out the sediment that collects at the bottom of the boiler. The surface blow-out usually consists of a dish or funnel-shaped receptacle set with its face vertical, as shown in Fig. 49. When the water-level is in line with this blow-out opening, the opening of the valve at the bottom will skim the impurities from the surface of the water quite readily. Oil may get into the boiler through the feed-water, and a considerable portion of it can be removed in this manner.

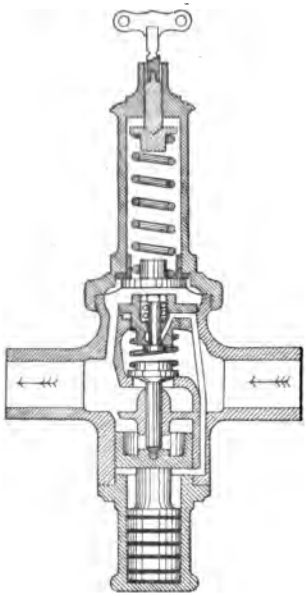


Fig. 48. "Mason" Reducing Valve. Pressure Regulated by Means of a Spring.

The bottom blow-out consists merely of a pipe leading from the bottom of the boiler outward. Both these blow-outs may be connected into one outlet.

In water-tube boilers a *mud-drum* is usually installed, which readily collects the solid matter, and the bottom blow-out is then connected with this mud-drum. Fig. 50 shows an arrangement of surface and bottom blow-outs as usually installed on a Scotch boiler of the marine type.

If the feed-water contains salt, which may frequently happen in marine practice, it is necessary that the boiler should frequently be blown out in order to remove the excess of salt. The density of the boiler water, if salt feed is used, should be carefully determined by a salimeter. The loss due to this frequent blowing out is considerable, as a large amount of heat is necessarily wasted; but it cannot be avoided, except by the use of fresh water, which sometimes may be impossible at sea.

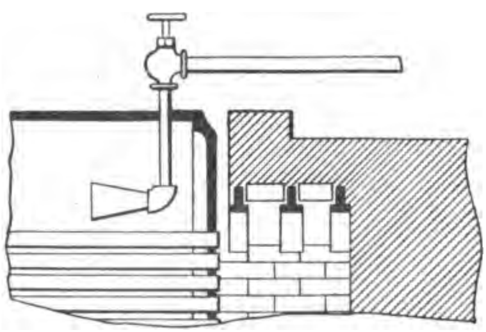


Fig. 49. Surface Blow-Out Installed in Boiler.

The blow-out pipe leading from the bottom of an externally-fired boiler through the brick setting, if not properly protected, may be burned off, owing to the heat of the fire. This pipe is frequently covered with asbestos or other fire-resisting material;

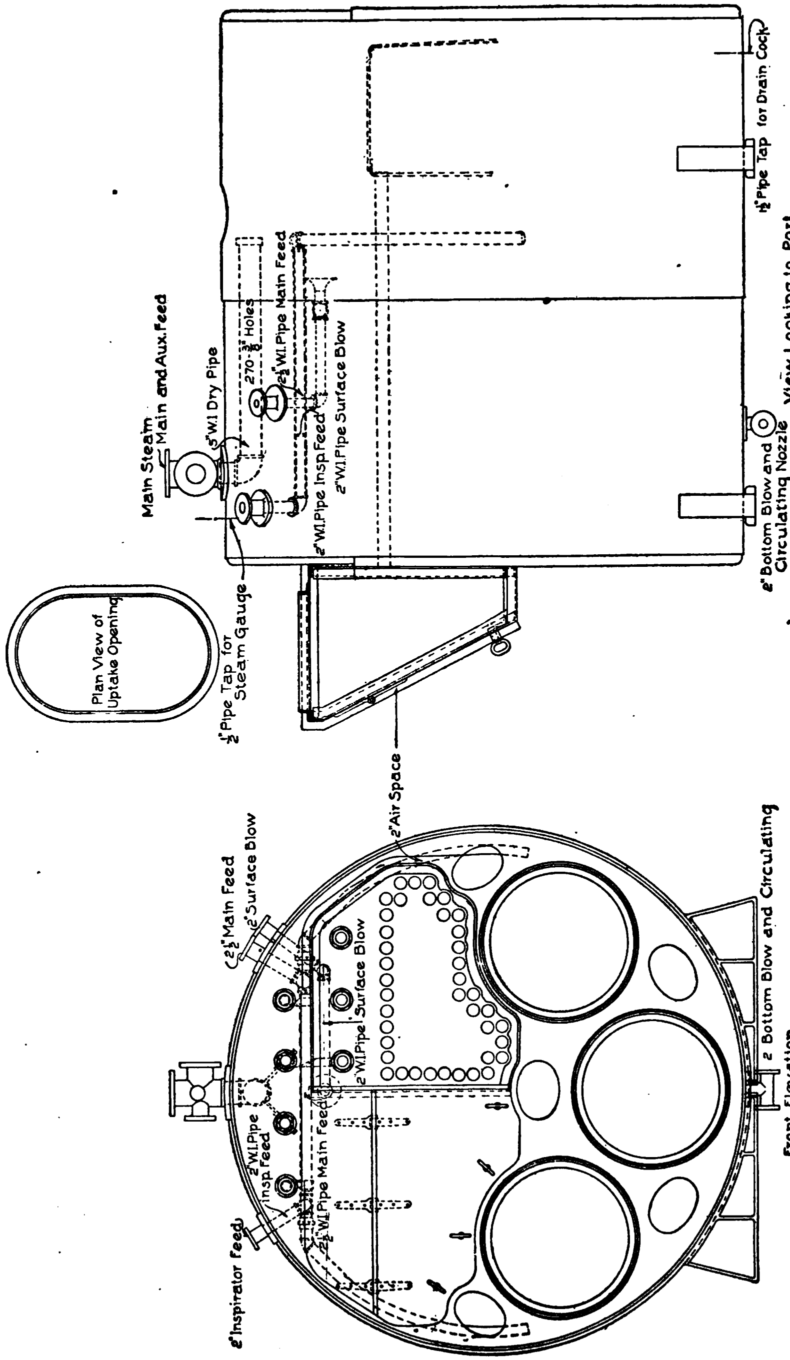


Fig 50. Scotch Boiler of Marine Type, Showing Arrangement of Surface and Bottom Blow-Outs.

but it can be best protected by the means shown in Fig. 51. A pipe connected to the boiler slightly below the water-level, runs out through the brick setting and connects into the main blow-out pipe. This causes a circulation of water continually to pass through the system, and prevents destruction of the blow-out pipe. When it is necessary to use the bottom blow-out, the valve *A* is closed, and the blow-off valve *B* is opened; otherwise, *B* is closed, and *A* is open while the water circulates.

The blow-out pipe is usually shut off by a cock, which, although not so easily operated as a valve, is more trustworthy. Frequently both a cock and a valve are provided. Should a small particle of sediment lodge on the valve-seat, it would be impossible to close the valve tightly, and a considerable leakage would result, while an inspection of the valve would not indicate whether it were completely closed or not. But a glance reveals the fact whether or not a cock is tightly closed. The cock is likely to stick because of corrosion or unequal expansion, but, if frequently opened, this difficulty is not of great weight. The plug and casing of the cock should not be made of the same material, as in that case they will more readily stick if the cock remains closed any length of time.

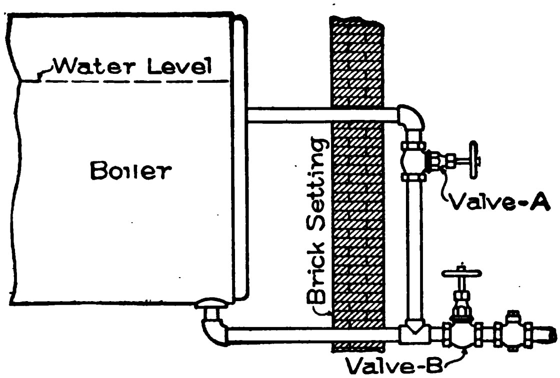


Fig. 51. Method of Protecting Bottom Blow-Out Pipe by Means of Circulation Pipe Connected to Boiler.

FEED APPARATUS

Perhaps the most important of all auxiliaries connected with the boiler is the feed apparatus. This is vital; for, if the feed is interrupted and the water runs low in the boiler, not only is there danger of damaging the boiler itself, but a disaster may follow of far greater concern. For marine purposes—and the same is true to a considerable extent in stationary work—at least two independent feed systems should be provided. In marine work, the main feed-pump draws water from the filter box or feed-water heater, and pumps it into the boilers under ordinary conditions. There should be a by-pass around this pump, and the feed line should be connected by means of a valve to what is known as the *donkey pump*, which may be used for auxiliary feed purposes in case the main pump is damaged or needs repairs in any way.

Both these pumps draw from and discharge into the same feed line; but, to provide against emergencies, there is usually a cross-connection to the sea, so that sea water may be had if necessary. While in port, when the main engines are not running, and consequently when the feed-water cannot be heated economically, an injector is almost invariably used. On land it is usually considered sufficient to install an injector in addition to the feed pump, although in large plants an auxiliary feed pump should be installed as well. In a small plant the fireman usually attends to the water; but on board ship and in large plants, a water tender is usually provided, whose business it is to keep the water in the boiler at the proper level. His task may be materially lessened by some automatic arrangement, so that if the water discharged into the hot well from the condenser rises above the normal level, a float will open the valve leading to the feed-pump and increase the rapidity of its stroke. This will reduce the level of the hot well or filter box, as the case may be.

Such an arrangement as this will keep a fairly uniform level of water in the boilers; and if a surface condenser is employed, and all the condensation is pumped back into the boilers, the water-level will remain constant except for slight leakages of steam and for the possibility of improper action of the feed-pump. Leakage of steam can be made up from the supply of fresh water. At sea, salt water may have to be used for this purpose although its use is objectionable.

There is a considerable difference of opinion as to where the feed-water should be introduced into the boiler, although the consensus of opinion seems to be that it should enter not far from the water-line. In stationary practice, the feed-water is introduced at the rear of the boiler near the bottom; but this is open to grave objections, for the feed-water, being comparatively cool and being introduced into the coldest part of the boiler, naturally tends to become dead water and to retard proper circulation which is essential to economical steaming and often essential to the safety of the boiler itself.

The best place for introducing the feed-water will naturally depend upon the type of boiler, and the service for which it is intended. If the entering water is of high temperature, it might enter near the bottom of the boiler. But if the feed-water is comparatively cold — and it is always colder than the water in the boiler and the surrounding steam if the circulation is good—great care must be taken that it does not strike directly against the hot boiler-plates, as it might thereby cause local contraction and possibly a serious leak, and it should be introduced in such a way as to make sure of its aiding the natural circulation of the boiler.

The higher the steam pressure in the boiler, the more difficult becomes the problem of feed, and the more danger there is of injury to the boiler by the comparatively cold feed-water striking hot plates. It is a universal practice in marine work, and a common practice on land, especially for internally-fired boilers, to cause the feed to enter above the water-level near the center of the boiler; then branching off into two pipes, one leading to each side through the steam space until the side of the boiler is reached; and then running downward toward the bottom. The feed-water, which very likely has been previously heated by a feed-water heater, is still further heated by its passage through this feed-pipe, which is in direct contact with the live steam of the boiler. This internal feed-pipe, turning down at the sides, causes the water to strike the outer shell of the boiler which is the most remote from the fire, and this downward motion materially assists the circulation in the boiler. When this arrangement of feed is adopted (see Fig. 50), care must be taken that the lower end of the feed-pipe is well below the low-water level. If the end of the pipe is alternately immersed in water and then exposed to steam, violent explosions in the pipe are likely to follow, although they are likely to do nothing more serious than break an elbow or frighten the attendants.

In stationary practice, it is quite common to admit the feed-water into the steam space through a horizontal pipe entering it through the tube-plate a few inches below the low-water level, and terminating in a perforated pipe of large diameter. This method distributes the feed-water admirably, and allows it to become considerably heated before it reaches the bottom of the boiler. If the feed-water contains a considerable amount of magnesia or calcium carbonate, holes so arranged in the feed-pipe are likely to become clogged and the feed interrupted. Water of this sort should be fed into a trough, or the feed-pipe be opened at the top by a long slot, so that the feed-water may overflow. The trough in this case forms an admirable mud-drum or sediment collector.

In internally-fired boilers of the "Cornish" or "Lancashire" type,

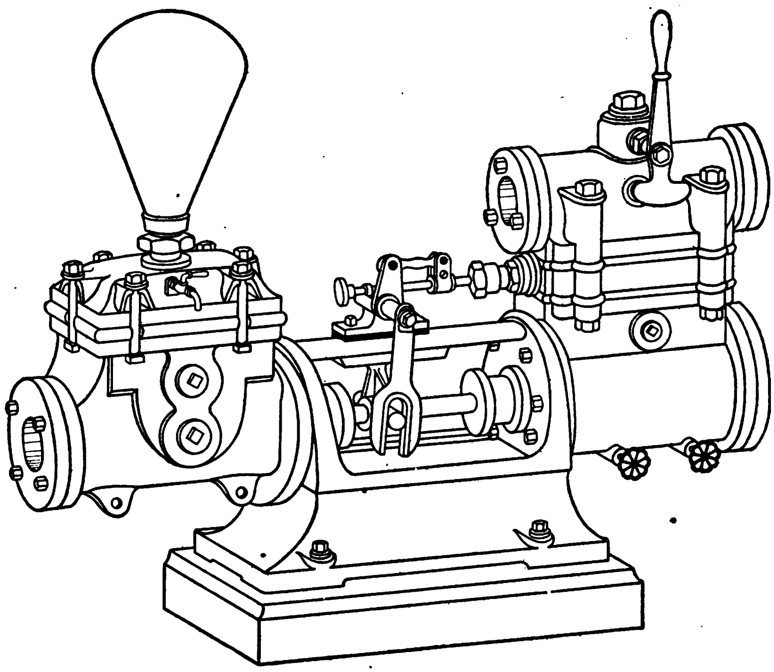


Fig. 52. Steam-Driven Boiler Feed-Pump.

the feed is usually delivered near the bottom through a horizontal pipe—either through the front end or by a vertical pipe through the crown. This method is not conducive to the best circulation.

In addition to these effects on circulation, there are other grave objections to introducing feed-water near the bottom of the boiler; for, should anything happen to the feed-pump, or a piece of scale lodge under the check-valve, the water might be almost entirely blown out of the boiler before the difficulty could be discovered or remedied.

If the pipe enters in the vicinity of the low-water level, no water could be drawn out below this point.

The feed supply should always be regulated so as to keep the water-level as nearly stationary as possible; this is not only much more economical, but also far better for the boiler, than to wait for the water-level to fall and then feed a few inches rapidly. The sudden introduction of a large volume of comparatively cold feed-water, causes local contraction of the plates, and hence tends to cause leakage;

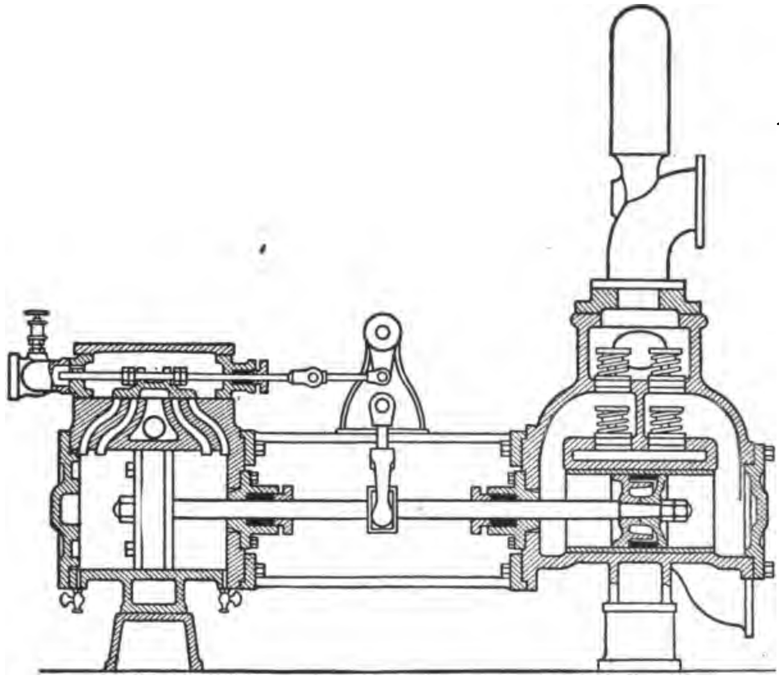


Fig. 53. Section of "Worthington" Duplex Steam Pump.

moreover, it necessitates irregular firing if anything like a uniform steam pressure is to be maintained.

Sometimes the feed-water is forced into the steam space in the form of a fine spray. In this way it not only is thoroughly heated before mingling with the water in the boiler, but the air is got rid of; and salts, such as sulphate of lime, insoluble at high temperatures, are immediately precipitated. But the advantage of introducing the feed-water in a body so as to produce useful circulating currents, should not be overlooked.

If several boilers are attached together in the form of a battery, each should be supplied with an independent connection to feed-pipe. Otherwise a damage to the feed-pipe in one boiler might affect the others. Moreover, if several boilers are fed from one pipe, the pressure in each of them being slightly different, an excess of water will naturally be fed into the boiler having the *least* pressure, whereas it is usually the case that the most water is needed in the boiler having the *greatest* pressure. The automatic float previously referred to, can regulate the amount of water fed into boilers only in a general way, through providing a method by means of which all the condensation is fed back into some of the boilers; but the quantity of feed which is led into each individual boiler must be watched and regulated by the water tender, who can open or close the individual valves as desired.

Pumps. Boilers are usually fed by a small, direct-acting *steam pump* placed near the boiler. Although these pumps require a large steam supply per horse-power per hour, the total amount of steam used is small because the work done is small A more economical pump is the power pump driven by the large steam engine; but in this case the rate at which water is supplied is not easily regulated to the demand of the boiler. Power pumps are usually arranged to pump a larger quantity of water into the boiler than is required, the excess of water being allowed to flow back into the suction pipe through a relief valve.

The pump shown in Fig. 52 is well adapted for feeding boilers. In Fig. 53 is shown the section of a duplex "Worthington" steam pump. The action of each of these two types is similar. Steam, controlled by valves, drives the piston in the steam cylinder, which moves the plunger in the water cylinder, since both are fastened to the same rod. The movement of the plunger forces a part of the water in front of it up through the valves into the air-chamber, and through the pipes into the boiler. On account of the partial vacuum caused by the movement of the plunger, water will be drawn from the suction pipe, through the valves, into the pump cylinder, filling the space left by the movement of the plunger. During the return stroke, this water is forced up into the air-chamber, and a like quantity enters the other end of the pump cylinder. The valves are kept on the seats by light springs, until the pressure on the bottom side is sufficient to lift them and allow water to flow through.

When two pumps are placed side by side, and have a common delivery pipe, the machine is called a *duplex pump*. It is usual to set the steam valves so that when one piston is at the end, the other is at the middle of its stroke. A duplex pump having a large air-chamber and valves set to act in this manner, delivers water with an approximately constant velocity.

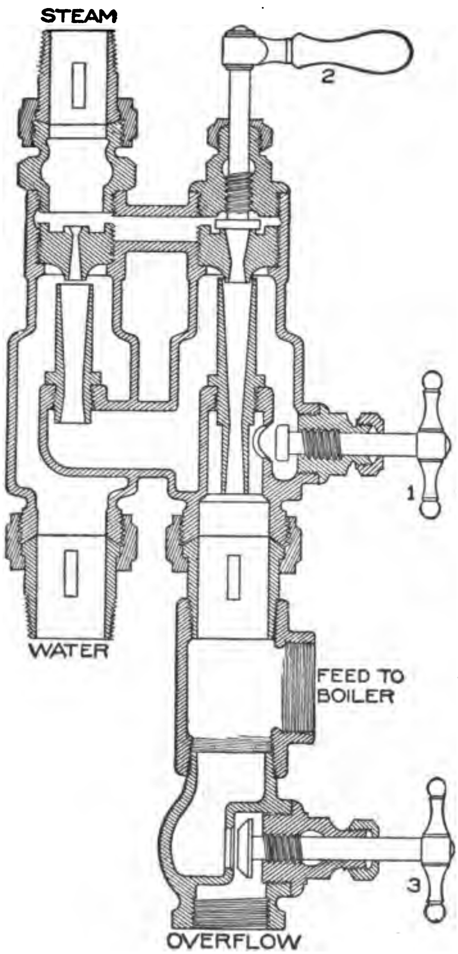


Fig. 54. Sectional View of "Hancock" Injector.

Injectors. Water may be forced into a boiler by an *injector* or *inspirator*. By means of this instrument, the energy of a jet of steam is used to force the water into the boiler. That there is sufficient energy to do this work is evident from the fact that each pound of steam, in condensing, gives up about 1,000 B. T. U., and a B. T. U. is equivalent to 778 foot-pounds. Not all the energy of the jet of steam is used in forcing water into the boiler; some is wasted, and much is used to heat the feed-water.

The action of the injector is briefly as follows: The steam escapes from the boiler with great velocity, and, as it passes through the cone-shaped passage, draws air along with it, thus creating a partial vacuum in the suction pipe. Atmospheric pressure forces water up into the suction pipe, and the jet of steam which it meets is partly condensed.

The energy of the jet carries the water along with it into the boiler.

Experiments show that the injector, if considered as a pump, has a very low efficiency. When used for feeding a boiler, it has a thermal efficiency of nearly 100 per cent, since all the heat of the steam passes to the water except the slight amount lost in radiation. The pump, however, has one great advantage over the injector; it can force hot water from a heater into the boiler, while an injector can be used only with cold or moderately warm water.

Figs. 54 and 55 show the interior section and exterior of a "Hancock" inspirator. To inject water to the boiler, first open overflow valves 1 and 3; close valve 2; and open starting valve in the steam pipe. When the water appears at the overflow, open 2 one quarter-turn, close 1, and then close 3. The inspirator will then be in operation. When the inspirator is not working, open both 1 and 3 to allow water to drain from it.

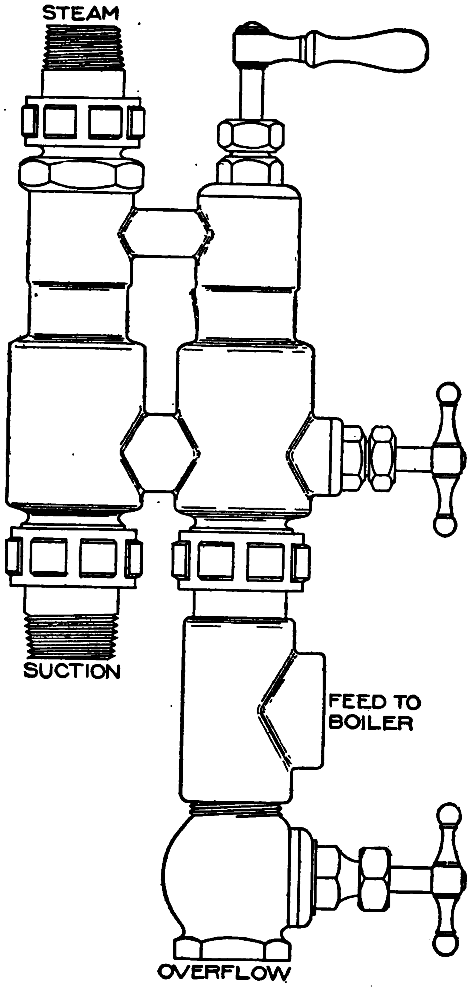


Fig. 55. Exterior View of "Hancock" Injector.

Both temperature and quantity of delivery water can be varied by increasing or decreasing the water supply. When the water in the suction pipe is hot, either cool off both pipe and injector with cold water, or pump out the hot water by opening and closing the starting valve suddenly.

Circulating Apparatus. There is always more or less danger in starting a fire under a boiler. If the circulation is poor, the result will be that not only will the water be of an uneven temperature, hot near the top and cold at the bottom, but the boiler shell is likely to be subjected to severe strain, owing to the difference of temperature arising from the stagnation of the cold water near the bottom. The fire must be started slowly, and a considerable time consumed in getting up steam. To overcome the difficulty of poor circulation, several mechanical devices have been applied.

The first device tried was a *hydro-kineter*—a sort of injector—in which jets of steam driven through a conical nozzle drew in the surrounding water. This was so arranged as to induce the cold water to flow from the bottom toward the top, where it was more intensely heated. This arrangement is efficient, but slow of action. In large marine boilers—in which the fire is cautiously started, as is proper—the temperature at the surface of the water, four hours after lighting up, has been found to be as high as 205°, while at the bottom it was only 73°. Several observations with a hydro-kineter in action have shown the temperatures to be 205° and 144° respectively. It was six hours more before the temperature was equalized throughout.

In naval vessels, where it is frequently necessary to raise steam rapidly, this device is altogether too slow. It has, moreover, two other drawbacks. There must be an auxiliary boiler under steam pressure, and it will cease to act when the temperature and pressure of steam in the main boiler has reached that in the auxiliary boiler. The steam jet, in the American Navy, has been replaced by a jet of feed-water forced through a conical nozzle. This arrangement answers very well so long as steam is being drawn from the boiler; but when the boiler is at rest and steam is being raised, it is inoperative.

The best service can be had by means of small centrifugal pumps fixed beside the boilers, which take water from the bottom of the boilers and discharge it a little below the water-level. The pumps may be turned by hand while raising pressure, and may be worked by steam when sufficient pressure has been attained. A small engine of perhaps 1½ horse-power is sufficient to give a proper circulation to a large boiler. With such a circulating device, steam can be raised with safety, in a comparatively short time.

Evaporators. No engine can be run without a certain loss of water, due either to a slight continuous leakage or to blowing off. In stationary practice, this loss can be readily made up by the application of fresh water; but at sea it is seldom possible to carry a sufficient amount of fresh water, and the make-up must be had either from sea water, or from fresh water provided by the use of an *evaporator*. The evaporator is really a small boiler, the water in which is

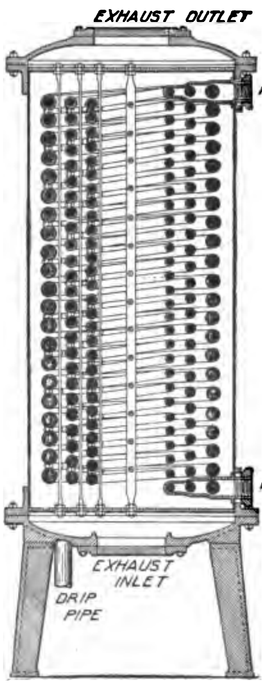


Fig. 56. Feed-Water Heater, Closed Type.

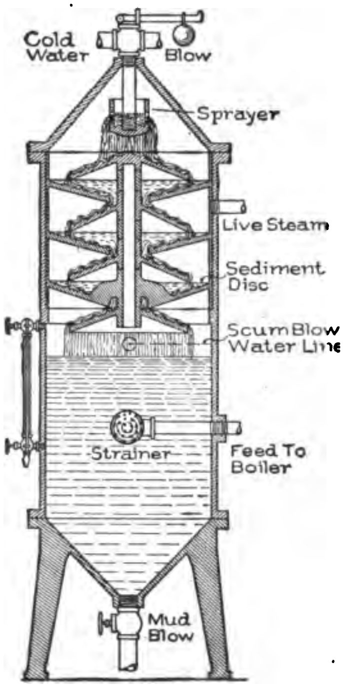


Fig. 57. Feed-Water Heater, Open Type.

heated by a steam coil supplied from the main boiler. The evaporated water—called the *evaporation*—passes into the condenser and then becomes a part of the regular feed water.

In a single evaporator, if the evaporation passes directly to the condenser, its heat is lost to useful work. To provide a more economical arrangement, multiple evaporators are installed, which consist of a series, the evaporation from the first passing into a coil in the bottom of the second; the water in the second condenses the evaporation from the first, while at the same time the evaporation from the first helps to heat the water of the second. The steam and water pass through the series of heaters in opposite directions.

It is a rule in the French Navy, to provide 380 lbs. of fresh water per hour for each 1,000 indicated horse-power; this provides for a loss of about 2 per cent without drawing on the reserve supply, which is 4,500 lbs. for the same amount of power.

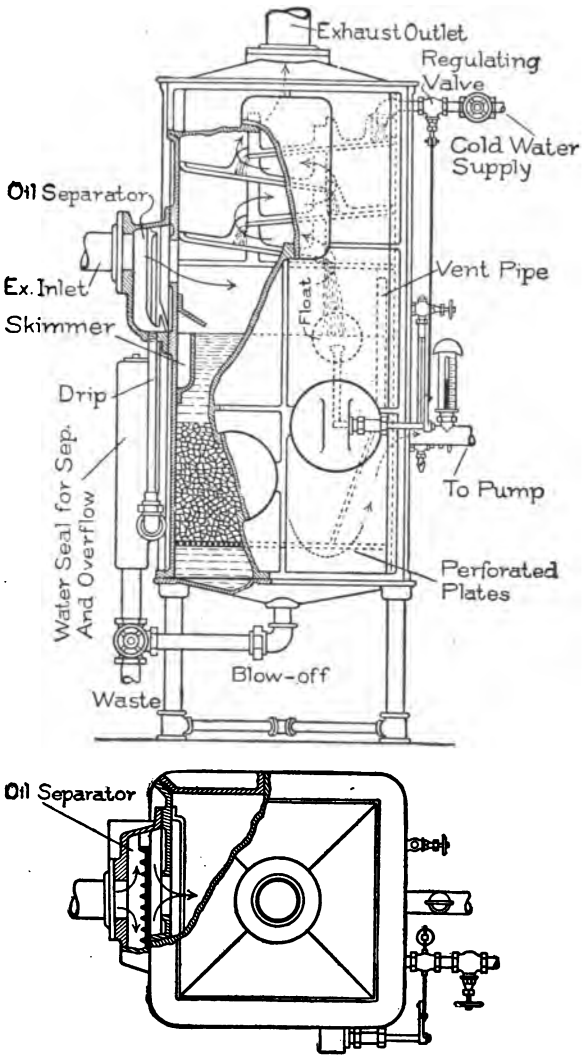
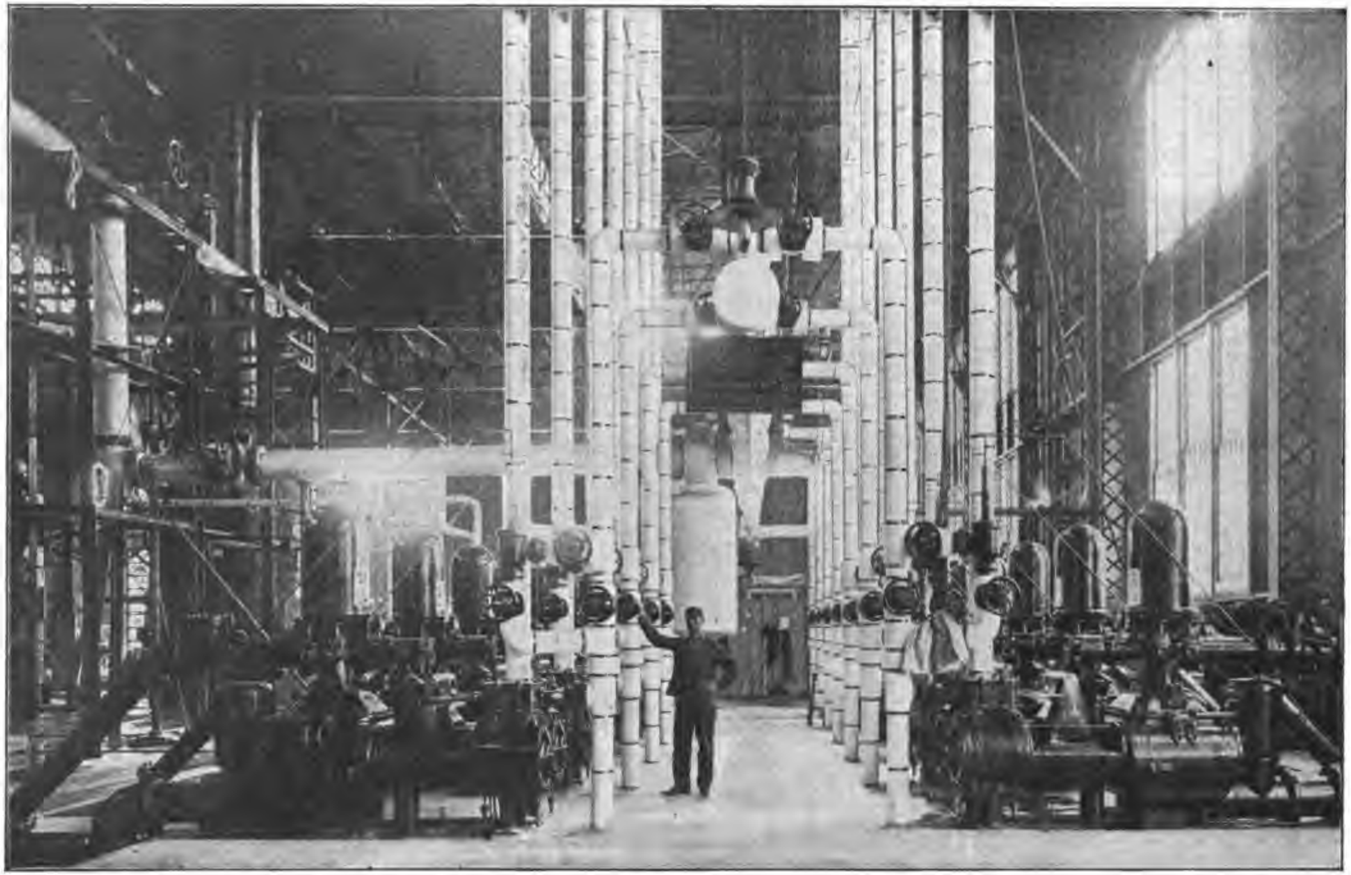


Fig. 58. "Cochrane" Combined Feed-Water Heater and Purifier, Open-Heater Type.

The evaporator may be arranged to communicate with a low-pressure valve-chest, in which case the evaporation may be made to do work in a low-pressure cylinder of a triple-expansion engine before entering the condenser, or it may be connected with the feed-water heater if the exhaust steam is inadequate.

Feed-Water Heaters. The introduction of feed-water at a high temperature increases the economy and tends to prolong the life of the boiler. The injurious effects from unequal expansion are dimin-



BOILERS AND CONNECTIONS, ST. LOUIS EXPOSITION.
Covered with Carey's Magnesia Coverings.

ished; and when the feed is warmed by exhaust steam or by the waste gases in the uptake, the saving of fuel is considerable.

If this gain comes from waste gases or exhaust steam, which would otherwise make no return for their heat, the gain is clear; but there is no gain in thermal economy by heating feed-water with live steam directly from the boiler.

There are several ways of heating the feed-water. In condensing engines, the feed-pump discharges from the condenser into the hot well, and the water is drawn from the hot well at a temperature of 100° to 140° F. This, however, if the pressure is over 100 lbs., is entirely inadequate; and for the best economy, feed-water at this temperature should be passed through some form of feed-water heater. In the non-condensing engines, it is absolutely necessary that in some way the feed-water should be heated by the exhaust steam or by waste gases from the chimney, the apparatus in the first case being called a *feed-water heater*, and in the second an *economizer*.

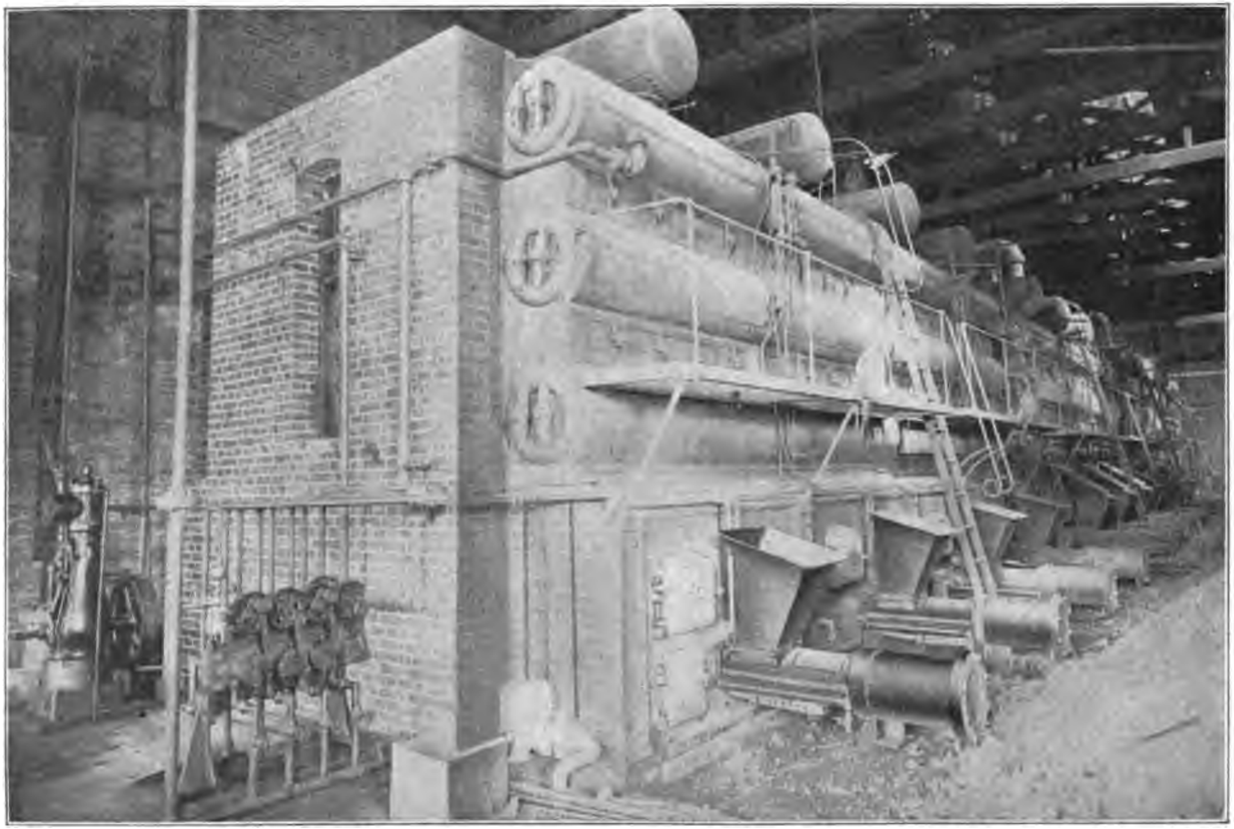
The feed-water heater may be arranged so that it will not only heat the water, but will at the same time purify it, precipitating the calcium and magnesia salts, which collect on suitably prepared plates, and gathering, at the bottom of the heater, dirt and other sediment that would injure the boiler.

There are two types of feed-water heater—the *open*, which is frequently used in land work; and the *closed*, which may be used either on land or at sea. In the open heater, the steam raises the temperature of the water by mingling with it in direct contact. The closed type of heater resembles in its action a surface condenser; the steam used for heating purposes surrounds tubes which contain the feed-water, or the water circulates about tubes through which the heating steam passes.

Fig. 56 shows a feed-water heater of the closed type, the exhaust steam heating the feed-water within the tubes. The heater shown in Fig. 57 is of the open type, the feed-water becoming heated and depositing sediment while flowing from one tray to another.

The "Cochrane" heater, Fig. 58, is a combined heater and purifier of the open-heater type, the water entering at the top and flowing in a thin sheet over a series of trays. The exhaust steam enters through the oil separator, and rising among the trays, heats the water to about 210° F, the action being similar to that of a jet condenser.

The gases held in solution in the feed-water are liberated by the heat, and escape into the atmosphere; while the mineral impurities in solution, which cause scale, are precipitated by the heat, and are deposited on the trays instead of on the plates and tubes of the boiler. The impurities, mud, clay, etc., settle to the bottom, because of the large surface and consequent low velocity of the feed-water through the heater, and are readily removed. Coke, hay, etc., are used for filters, a strainer being constructed so that the hay or coke will not enter the pump. The impurities, having less specific gravity than the water, collect at the surface, and are removed by flushing.



JONES UNDERFEED STOKERS IN STATION OF THE TOKYO ELECTRIC CO.,
TOKYO, JAPAN.

BOILER ACCESSORIES

PART II

STEAM SEPARATORS

Priming. Steam is said to be *wet* or to be *superheated,* according as it has an excess of moisture or an excess of heat. Wet steam not only is uneconomical, because it carries a considerable amount of heat into the engine in the form of water, which cannot do useful work, but, if a considerable amount of water gets into the engine, it is really dangerous, for it may so completely fill the clearances that the piston will strike a blow against the cylinder-head sufficient to break it. The water in the pipes, moreover, may cause a serious hammering, which not only is exceedingly annoying, but may be actually dangerous, for a severe water-hammer may break the joints of the steam pipes, and a considerable quantity of escaping steam at high pressure would be exceedingly dangerous to the lives of the engine-room attendants. This especially would be true on board ship, where the engine-room is small, the supply of air meager, and the means of escape limited.

A considerable amount of water may be deposited in a sag in the pipe line, and would undoubtedly remain there for a considerable length of time if the pressure in the boiler did not fluctuate; but a sudden rise of boiler pressure would likely cause this water to pass bodily through the pipe toward the engine. Moisture is carried directly from the boiler as a result of *priming.* This is caused by steam bubbles which, instead of bursting, become connected on the surface of the water, forming a foam, half-liquid, half-gaseous, which fills the steam space and passes out of the steam pipe. Priming may be due to fluctuations of boiler pressure or to the presence of dirt, oil, or other foreign matter. The smaller the free surface of the water in the boiler, the more likely the water is to prime. Boilers will frequently prime badly under forced draft, when otherwise there would be little trouble.

Priming may be detected from the unusual behavior of the water in the gauge-glass, or from the hammering in the steam pipes or cylinder. To avoid a breakdown under such conditions, the speed of the engine should be reduced, the drain-cocks of the cylinders and pipes opened, and the fires eased down. Sometimes, by suddenly shutting the main stop-valve, the pressure in the boiler can be increased sufficiently to overcome the difficulty.

Almost any boiler is likely to prime to some extent; and to obtain as dry steam as possible, several devices are employed. On the top of stationary boilers and locomotives, a *steam dome* is frequently built, from which the steam is drawn, the idea being that less moisture will be found here than if the steam be drawn directly from the main portion of the boiler. In marine work, and sometimes in stationary plants, a *dry-pipe* is used (see Fig. 50). This is merely a large pipe inside the boiler, from which the steam is drawn. The pipe is near the top of the boiler, and the upper side of it is perforated with holes through which the steam may pass. A considerable amount of moisture is in this way prevented from leaving the boiler.

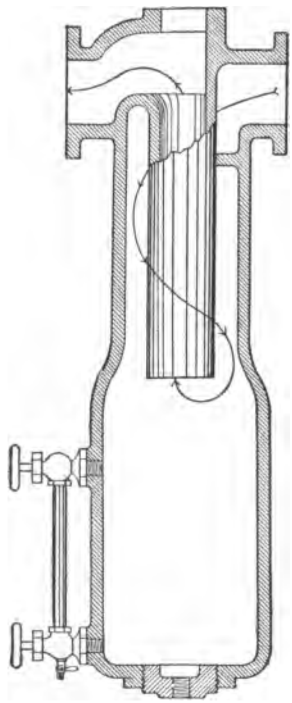


Fig. 59. "Stratton" Separator.

The moisture in steam can be reduced by the familiar process of superheating; but if this, for any reason, is impracticable or undesirable, a steam separator may be used for the purpose of extracting the moisture that comes from the priming of the boiler or from condensation in the steam pipe.

Separators. There are several forms of separator; but all are designed on the general principle that if the direction of the steam current is suddenly changed, or if it is diverted upward and then downward, the water will be separated from the steam and will fall to the bottom of a suitable receptacle. The depth of water collected in the bottom of the separator is readily indicated by a gauge-glass, and it may be drawn off as desired. To prevent the possibility of flooding the separator, it is well to connect it with an automatic trap which will empty it without close attention from the engineer. It is needless, of course, to say that the trap from this separator should be connected to the hot well, and the drip should be returned to the boiler with the loss of as little heat as possible.

In the "Stratton" separator, Fig. 59, the steam enters at one side of a cylinder, flows downward, and then upward through a pipe in the middle. Dry steam escapes from a pipe near the top, on the opposite side from which it enters. The separated water is drained at the bottom.

The "Cochrane" steam separator, shown in section in Fig. 60, is of the baffle-plate type. The branches for the entrance and exit of the steam project from each side of the spherical head. Another branch from the bottom provides for connection with the well. The baffle-plate, which is cast as a part of the head, is ribbed, or corrugated, and has ports at each side for the passage of steam. The area of the ports is large, to prevent loss by friction. A small pipe is inserted in the plate on the outlet side at the bottom of the baffle-plate, to drain

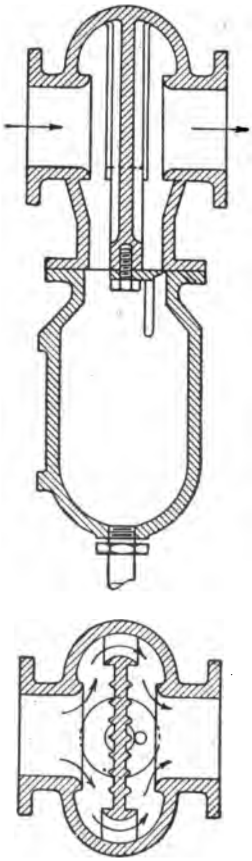


Fig. 60. Sectional Elevation and Plan of "Cochrane" Steam Separator.

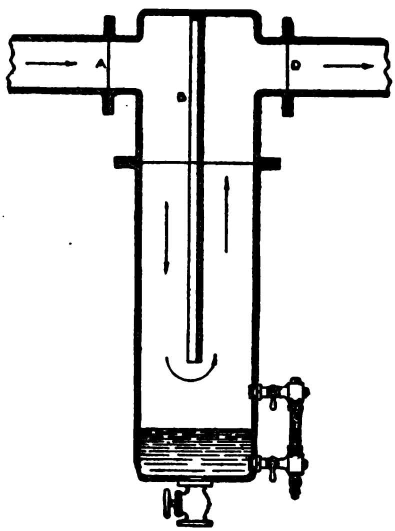


Fig. 61. Separator Designed for Connection to Main Steam Pipe near Engine.

any condensation in the outlet chamber. Steam, entering at the left-hand opening, strikes the baffle-plate and passes to the outlet chamber by means of the two side passages, as shown in the plan, Fig. 60.

A form of separator which is fitted to the main steam pipe near the engine, is shown in Fig 61. Steam enters at *A* and strikes the dash-plate *B*; any water coming with the steam is separated and falls to the bottom. The steam takes the direction indicated by the arrows, and flows out at *D*. This separator is fitted with a gauge-glass which is similar to a boiler gauge-glass.

STEAM TRAPS

Steam traps are used for collecting the water of condensation from steam pipes. They consist of a receptacle with an inlet and outlet valve so arranged that the condensation which collects may flow out, but steam cannot pass.

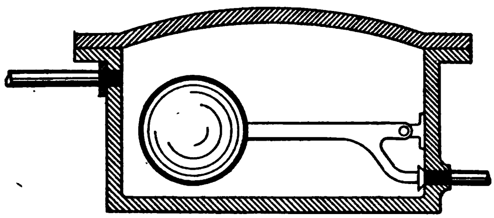


Fig. 62. Simple Steam Trap Operated by Float.

In the *float* trap shown in Fig. 62, the float rises and falls with the change in water-level. When the water-level rises above a certain point, the float opens the discharge valve. The trap shown in Fig. 63 is similar, the float being replaced by a weight *W*, which is nearly counterbalanced by the weight *T*. The raising of *W* by the water opens the valve *V*.

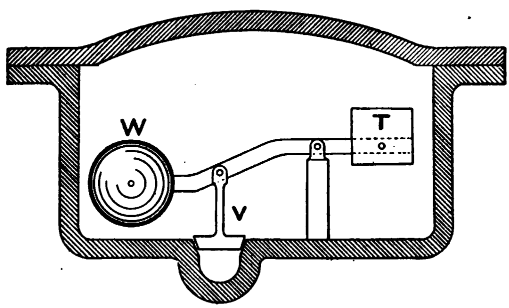


Fig. 63. Steam Trap Operated by Nearly Counter-balanced Weight.

There are other forms called *bucket* traps. In the one shown in Fig. 64, the water enters at *W*. While there is only a little water around the bucket *F*, it floats, and the valve *V* is closed; but when the water rises high enough to flow over the edge, the weight of water in the bucket causes it to sink, and opens the valve *V*. Water is forced up the passage *M*, and out through the pipe *N*, by the pressure of the steam on the surface of the water surrounding the bucket.

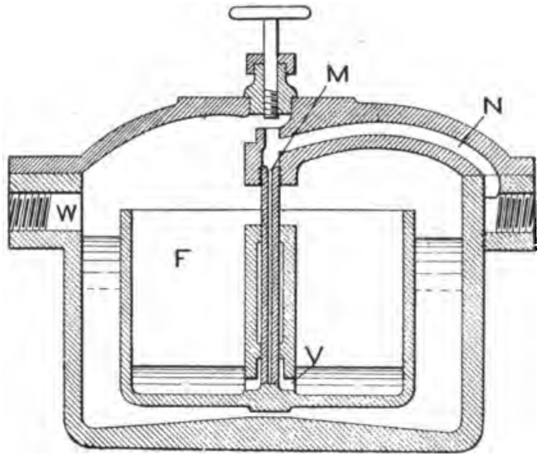


Fig. 64. Bucket Type of Steam Trap.

Another form of trap, called the *differential* steam trap, depends upon a head of water acting on a flexible diaphragm. Water enters at either top or bottom by the pipes *E*, Fig 65. When the water-level rises, it fills the chamber *G* and the pipe *N*. This causes a pressure on the under side of the diaphragm greater than that caused by the spring *H*, which spring acts on the upper side of the diaphragm and tends to keep the valve open. While the pressure below the diaphragm preponderates, the valve *P* remains closed. When the water rises and fills the chamber *J* so as to flow down the pipe *M*, the water-pressure on the upper and lower side of the diaphragm will become equal, because the head of water in *M* is practically the same as that in *N*. The spring will now open the valve *P*, and water will be discharged from the pipe *I*. When the head in *M* falls, the pressure on the under side of the diaphragm again becomes greater, and the valve accordingly closes.

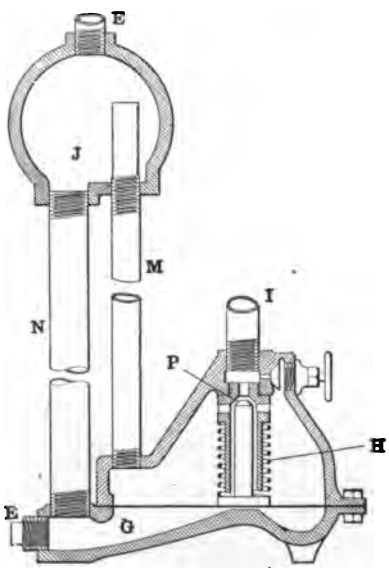


Fig. 65. Differential Steam Trap, Operated by Water-Pressure on a Flexible Diaphragm.

Return Traps. Traps that are used for returning water of condensation to the boiler are called return traps. There are a variety of forms, but the principle of action in all is similar, and is shown in Fig. 66. *B* represents the boiler, and *T* the trap, which is placed a few feet above the boiler. The trap is supplied with steam from the boiler. It is also connected with the boiler by the pipe *P*, in which is a check-valve at *C*. Water of condensation enters the trap through the pipe *E*, in which is a check-valve *H*, until it reaches a depth sufficient to raise the float *F*, which opens the balanced steam valve *V*,

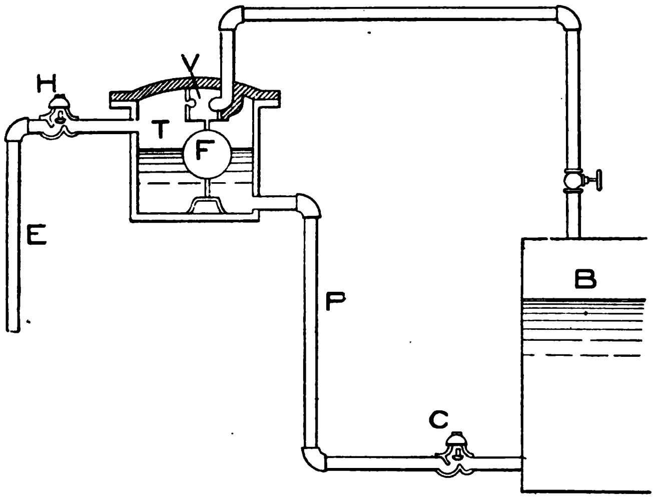


Fig. 66. Diagram Illustrating Operation of Return Trap.

called an *equalizing valve.* Steam from the boiler then enters the trap and equalizes the pressure. Since the pressures are equal, water in the trap, because of its height above the water-level of the boiler, will flow to the boiler until the level in the pipe *P* is nearly the same as the water-level in the boiler. As the water-level in the trap falls, the float *F* drops, and the equalizing valve is closed.

In some forms of return traps, buckets are used instead of floats.

CALORIMETERS

Steam from a boiler is generally accompanied with more or less moisture. This, being mechanically suspended in the steam, cannot readily be measured without the use of special apparatus. An instrument by means of which the percentage of moisture in steam can be determined, is generally called a *calorimeter*. There are several different types of this instrument, only three of which will be described.

The Barrel Calorimeter. This was invented by the distinguished engineer, Mr. G. A. Hirn, and is not only one of the earliest of these devices, but is by all means the simplest and most inexpensive form of calorimeter in practical use. It is shown in Fig. 67. The essential apparatus consists of a barrel holding about 400 lbs. of water, scales for weighing—and nothing more. A pipe with suitable connections leading from the boiler or steam main, conveys the sample of steam to be tested. This pipe should be provided with a valve, and on the end should be a piece of rubber hose which can readily be inserted in the barrel or removed. The principle of this calorimeter is extremely simple. As steam flows through the pipe, it is condensed by the water in the barrel, and the increase in the weight of the barrel after the test indicates the total amount of moist steam condensed, while the rise in temperature of the water in the barrel is an exact measure of the quantity of heat obtained from this moist steam.

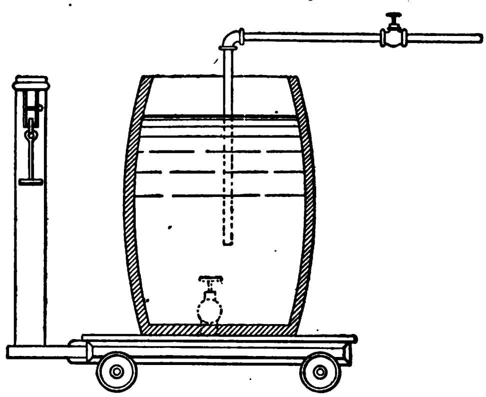


Fig. 67. Details of Barrel Calorimeter.

The steam tables give the number of B. T. U. in dry steam and hot water at various temperatures and pressures; and with this data and the above-mentioned observations made in the barrel, the percentage of steam and moisture can readily be determined.

The sampling pipe usually projects into the steam main a few inches, the end being perforated so that the sample will be drawn from a point near the middle of the pipe. An agitator should be placed in the barrel, so that the water may be thoroughly stirred and a uniform temperature maintained during the test.

To test a sample of steam by this method, fill the barrel about two-thirds full of cold water; place it on platform scales, and carefully note its weight and temperature. The weight of the barrel and fittings, when empty, should of course be known, so that the weight of the water alone can be determined. With the hose removed from the barrel, allow steam to blow through the pipe until it has become thoroughly heated. If the sampling pipe is long, it should be wrapped with hair felt or some form of lagging, to prevent condensation during the test. As soon as the pipe line has become thoroughly heated, plunge the hose into the barrel and allow the steam to blow through the water until it has become well heated. Shut off the steam, and carefully note the weight and temperature.

Suppose W = Final weight of water in barrel;
w = Weight of cold, condensing water before steam is turned on;
t_1 = Temperature of the cold water;
t_2 = Temperature of the hot water;
P = Absolute pressure of steam in steam pipe (gauge pressure + atmospheric pressure).

From the steam tables in the back of the book may be found:

q, the B. T. U. in one pound of the liquid contents of the moist steam;
q_1, the B. T. U. in one pound of the cooling water, before the steam was added;
q_2, the B. T. U. in one pound of this water after the steam has been added;
r, the heat of vaporization corresponding to the absolute pressure—*i. e.*, B. T. U. given up by one pound of steam condensed into water.

If x equals the percentage of dry steam contained in the supply pipe, $1 - x$ will represent the amount of priming.

$x\ (W - w)$ = the total amount of dry steam condensed;

$(1 - x)\ (W - w)$ = the total amount of moisture brought into the barrel by the moist steam.

If q_1 equals the heat in one pound of cooling water, then $q_1 w$ will equal the total heat in the barrel at the beginning.

For the same reason $q_2 W$ will equal the total heat after the steam has been condensed, and $q_2\ W - q_1\ w$ will equal the total amount of heat gained by the water in the barrel.

If r is the heat of vaporization, then $r\ x\ (W - w)$ will equal the B. T. U. contained in the dry steam; and if q is the heat of the liquid corresponding to the same pressure, then $q\ (1 - x)\ (W - w)$ will equal the B. T. U. contained in the moisture brought over by the steam. It is apparent that the sum of these two quantities will be the total number of B. T. U. brought from the steam main to the water barrel, and must be equal to $q_2\ W - q_1\ w$, the heat gained by the water in the barrel. The solution of this equation will result in a formula which will save some mathematical computations.

That the method may be perfectly clear, let us first consider a numerical example in full.

Suppose $w = 455$ lbs.
$W = 495$ lbs.
$t_1 = 50°$ F.
$t_2 = 140°$ F.
$P = 75$ lbs.
q (from steam tables) $= 276.9$
q_1 " " " $= 18.1$
q_2 " " " $= 108.2$

Then the total heat in the barrel after condensation, is equal to $(495 \times 108.2) = 53{,}559$ B. T. U.

The total heat before condensation was equal to $455 \times 18.1 = 8{,}235$ B. T. U. Therefore the heat brought over by the moist steam will be $53{,}559 - 8{,}235 = 45{,}324$ B. T. U.

Now, from the steam tables

$$q = 276.9; \text{ and } r = 898.8.$$

The heat given up by condensation of the dry steam will then be $898.8 \times (495 - 455)x = 40x \times 898.8 = 35{,}952x$; and the heat of the liquid in the moisture and condensed steam will be $40 \times 276.9 = 11{,}076$, making the total heat in the moist steam $= 11{,}076 + 35{,}952x$.

Therefore, $11{,}076 + 35{,}952x = 45{,}324$

$$35{,}952x = 34{,}248$$

$$x = 0.952$$

That is, every pound of moist steam contains .952 lb. dry steam and .048 lb. moisture; or we may say there was 4.8 per cent of priming.

The formula may be derived by the following algebraic work:

Total heat in bbl. after condensation $= W\,q_2$;

Total heat in bbl. before condensation $= w\,q_1$;

Total heat brought over by steam $= W\,q_2 - w\,q_1$;

Heat of liquid in condensed steam $= (W - w)\,q$;

Latent heat in dry steam $= x\,(W - w)\,r$;

Total heat in moist steam $= x\,(W - w)\,r + (W - w)\,q$.

Therefore,

$$x\,(W - w)\,r + (W - w)\,q = W\,q_2 - w\,q_1;$$

$$xr\,(W - w) = W\,q_2 - w\,q_1 - W\,q + w\,q;$$

or, transposing to a more convenient form,

$$x = \frac{w\,(q - q_1) - W\,(q - q_2)}{r\,(W - w)}.$$

The use of this form of apparatus is not especially to be commended, for it is liable to error, and a slight discrepancy in the weights or the temperatures may cause a large error in the result. In the above calculations, no allowance is made for loss of heat through radiation.

Separator Calorimeter. This instrument shown in Fig. 68, consists of a chamber A, into which is led a steam pipe D, bringing a sample of steam from the boiler or steam main. This pipe leads into an enlargement perforated with small holes, or into a chamber A as shown in Fig. 68. The calorimeter separates the moisture from the steam just as a steam separator does; and the exhaust, which is dry steam, passes out of the pipe , wherein is inserted a diaphragm containing small orifices, by means of which the quantity of steam flowing out can be calculated by thermodynamic methods. The exhaust steam can, of course, be led to some form of condensing apparatus, and the condensation weighed, if desired.

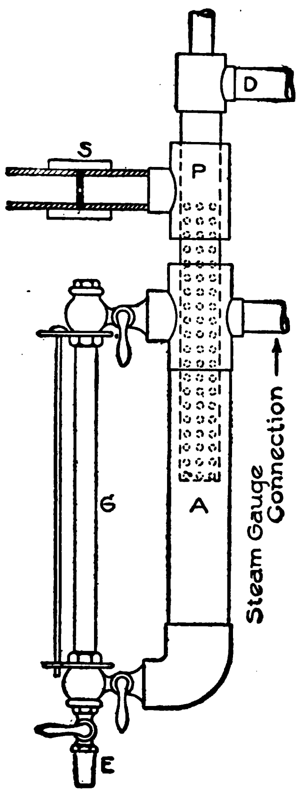


Fig. 68. Separator Calorimeter.

As the steam enters the calorimeter, the moisture is drawn toward the bottom of the chamber. The amount of water collected can readily be read from the gauge-glass at the side, to which a graduated scale should be attached.

The amount of moisture contained in the steam can be weighed directly by drawing it out of the gauge-cock E. The amount of dry steam is measured by its flow through the orifices, or by condensation.* If W = weight of steam discharged from the calorimeter,

*NOTE: For principles governing flow of steam through an orifice, consult any treatise on Thermodynamics.

and w = weight of water collected, then the percentage of priming will be $\frac{w}{W + w}$.

If only a small quantity of steam is used, an allowance must be made for condensation; but if the instrument is well lagged with hair felt or other suitable material, and a sufficient quantity of steam is used, the error from radiation may be neglected. Steam should be allowed to flow through the instrument until it has become thoroughly heated, before beginning the test.

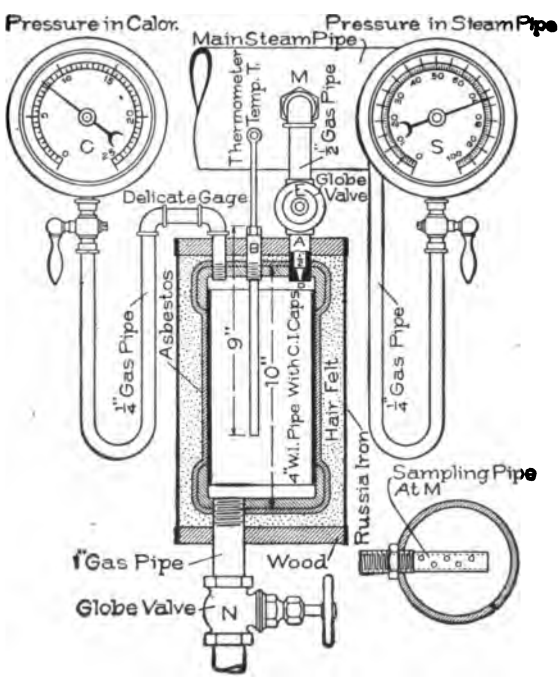


Fig. 69. General Arrangement of Throttling Calorimeter.

Throttling Calorimeter. This was invented by Prof. Cecil H. Peabody, and is made with varying constructive details. Fig. 69 shows the general arrangement. The mixture of steam and water from the boiler is taken from the main steam pipe through what is termed a *sampling* pipe. Various forms of this pipe are made; one arrangement consists of a pipe closed at its inner end, but having numerous holes ¼ inch in diameter drilled staggering around the sides. The calorimeter should be placed as close as possible to the main steam pipe; and the gauge for indicating the pressure in the main steam pipe should be placed on the latter and near the calorimeter. The gauge is sometimes connected to a tee on the pipe leading to the calorimeter; but it is better to have this gauge where the velocity of the flowing steam is less. A valve is placed in the pipe to the calorimeter, below which is inserted a nipple A having a small converging orifice D, about two-tenths of an inch in diameter and very carefully made. The object of such an orifice is to determine the weight of steam flowing through the calorimeter, so that an allowance can be made for the loss when testing an engine or boiler, where the net weight used is required. A cup B is screwed into the top, for holding an accurate thermometer. The cup is made of brass, and is filled with oil; but if mercury is used, the cup must be of iron or steel. A delicate gauge C, for determining the pressure in the calorimeter, and a pipe and valves at the bottom, complete the apparatus. The valve N is sometimes omitted, and a simple pipe used, as the throttling is best accomplished by use of the valve E or orifice D. All pipes leading to the calorimeter should be well covered with a good non-conductor.

To use the instrument, proceed as follows: Open wide valves E and N, to bring the apparatus to a uniform temperature; then gradually close E until the steam in the calorimeter is superheated; that is, until the temperature as shown by the thermometer is greater than that corresponding to the absolute pressure determined from the reading of the gauge C and barometric pressure. The result may now be calculated as follows:

x = Weight of steam contained in one pound of the mixture from the main steam pipe or other source;

λ_c = Total heat corresponding to the absolute pressure determined from the reading of the gauge C and barometric pressure; *

T = Temperature as shown by the thermometer;

t_c = Temperature of steam corresponding to the absolute pressure as determined by the reading of the gauge C and barometric pressure;

q_s = Heat of the liquid corresponding to the absolute pressure in the steam pipe;

r_s = Heat of evaporation corresponding to the absolute pressure in the steam pipe;

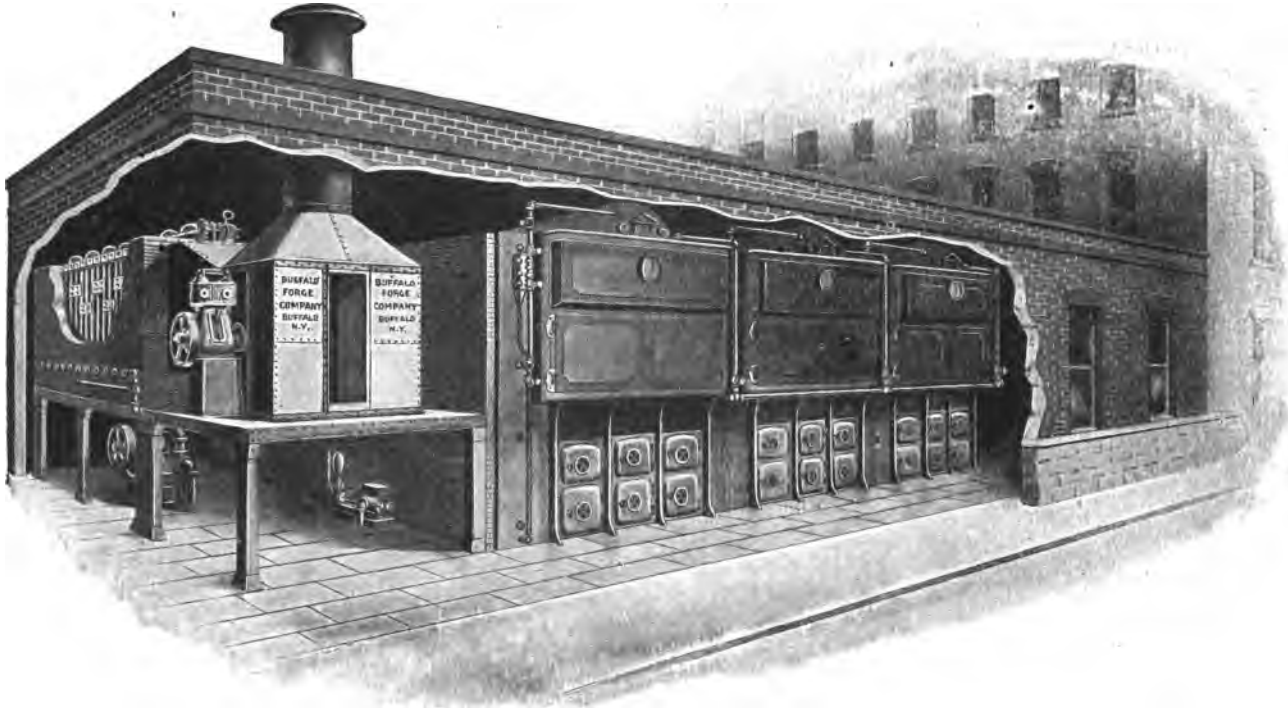
0.48 = Heat required to superheat the steam one degree Fahrenheit under constant pressure.

Total heat in 1 lb. superheated steam in calorimeter = $\lambda_c + 0.48\ (T - t_c)$ B. T. U.

Total heat in 1 lb. moist steam in steam main = $xr_s + q_s$ B. T. U.

These two quantities are equal; and x, being the only unknown quantity, the equation can easily be solved.

*NOTE: Some steam tables use H instead of the Greek letter λ (lambda).



MODERN BOILER HOUSE WITH INDUCED DRAFT AND ECONOMIZER.
Buffalo Forge Company.

$$x = \frac{\lambda_c + 0.48\,(T - t_c) - q_s}{r_s}.$$

Example. Barometric pressure, 14.78 lbs. Absolute pressure in main steam pipe, 87.78 lbs. Absolute pressure in calorimeter, 23.03 lbs. Temperature (T) = 260° F. Then,

$\lambda_c = 1{,}153.68$ $\quad q_s = 288.1$

$t_c = 235.28$ $\quad r_s = 890.88$

$$x = \frac{1{,}153.68 + .48\,(260 - 235.28) - 288.1}{890.88} = 0.984 \text{ pound.}$$

Or, in other words, 98.4 per cent of the mixture is steam; or the moisture = 1 — 0.984 = 0.016, or 1.6 per cent.

This form of calorimeter is suitable only for cases where the moisture does not exceed three per cent of the mixture. Its principle is based upon the assumption that there is no loss of heat, in which case steam mixed with a small amount of water is superheated when the pressure is reduced by throttling.

PIPING

Although piping can hardly be considered a boiler accessory, a few general remarks will not be out of place.

Pipes must not only be of sufficient size and strength, but should be so installed as to make ample provision for expansion due to the high temperature when they are filled with steam. The supports for long pipe lines should be arranged somewhat as shown in Fig. 70, which allows the pipe a considerable amount of lateral motion.

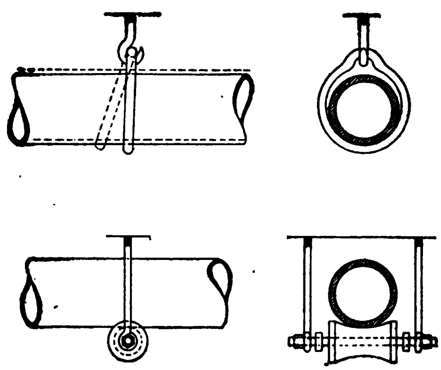


Fig. 70. Side and Transverse Sectional Views Showing Methods of Arranging Supports for Long Pipe Lines.

If the pipe line is long, an *expansion joint* must be provided. Sometimes a curved U-bend may be inserted in the pipe line, which of itself will have flexibility enough to provide for reasonable expansion. Or, if the steam main is not all in one line, a similar bend may be provided, with elbows and nipples, as shown in Fig. 71. In this case, any expansion of the steam main will cause the nipples to turn slightly in the elbows. This motion, of course, is slight, but it is sufficient to prevent rupture. U-bends and swivel-joints are hardly practicable in large pipe; and in such cases a *slip-joint*, made tight by a stuffing gland, is usually provided. If this is done, great care must be taken that the steam main is straight and in perfect alignment, as the pipe may otherwise bind in the expansion joint and cause much damage from leakage.

In marine work, especial care must be taken that the pipe lines are not so rigidly connected together that they will be injured by the working of the ship. This can readily be provided for by laying the pipe in such a way as to provide a simple form of swivel-joint.

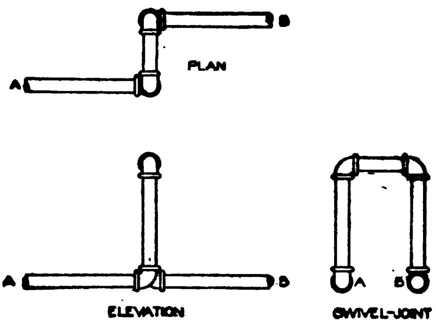


Fig 71. Method of Forming Swivel-Joint in Steam Piping to Counteract Effects of Expansion and Contraction.

The pipe lines should be as straight as possible, to prevent unnecessary friction of the steam and unnecessary condensation; and they should, if possible, be so installed as to leave no pockets wherein condensation may collect. If such a pocket is unavoidable, a drain must be provided, leading from the pocket to the steam trap, whence the condensation may be discharged into the hot well or filter-box, because the collection of water in steam pipes is a source of inconvenience and danger.

The pipe lines should be installed with sufficient slope, so that the condensation will readily drain to a convenient point whence it may be drawn off. This slope should be in the direction of the flow of the steam, as the water will not readily flow otherwise. Great care should be taken that the pipe lines nowhere sag, as such a depression will collect condensation. This may cause very little disturbance unless the pressure of the steam is suddenly raised, in which case the water is liable to flow bodily along the pipe; and if it does not enter the cylinder of the engine and cause damage there, it will cause a serious water-hammer which may rupture the elbows of the pipe and may endanger life.

Formerly, when low pressures were used, cast iron was a common material for a main steam pipe leading from the boiler to the engine, but the higher pressures of to-day require the best wrought iron or steel. In marine work, copper is commonly used; but with the advent of higher and higher pressures, copper fails to give the requisite strength, and it has to be reinforced with wire or iron bands. At pressures not over 150 lbs., copper pipes may be used, by the British Board of Trade rules, 15 inches in diameter; but at 200 lbs., copper pipes are not allowed over 10 inches in diameter. For large sizes, riveted iron or steel pipe may be used. For high pressures, cast-steel fittings are required by the U. S. Steamboat Inspection rules. There was always danger that the large copper pipe would burst; and it is now the common practice to use steel for such purposes.

Large steam pipe is made in sections which can be riveted together. The small sizes are fitted with the ordinary type of flange, and the sections may be bolted together, a suitable gasket being used between the two flanges to make a steam-tight joint. The flanges are machined perfectly smooth, and the packing may consist of rubber and fiber reinforced with wire insertion, or of asbestos, or of corrugated copper.

The true inside diameter of steam, gas, or water pipe is not always the same as the size of the pipe as popularly known. For instance, what is called "3-inch" pipe has an actual inside diameter of 3.067 inches, and 3.5 inches outside diameter. The actual sizes of pipe, inside and outside, can be found in any handbook or steamfitter's catalogue.

LAGGING

When steam pipes are exposed to the air, a considerable amount of condensation will collect in them, depending on the condition of the surface of the pipe, on the difference in temperature between the steam and the surrounding air, and on the velocity of the steam through the pipe. This condensation will cause a large amount of heat to be lost to useful work, and will make the dangers of water-hammer possible unless carefully drained. Tests have shown that about 2 B. T. U. are lost per square foot of pipe per hour per degree of difference in temperature. While the loss for a few hours is not likely to be great, yet, if taken for an entire year throughout a considerable length of pipe, the sum total will be very large indeed. The following table gives some idea of the loss of heat through bare pipe at 200 lbs. pressure:

HEAT LOSSES IN BARE PIPES

Condition of Pipe	B. T. U. Loss per Sq. Ft. per Minute
New Pipe	11.96
Painted Glossy Black	12.10
Painted Glossy White	12.02
Fair Condition	13.84
Rusty	14.20
Coated with Cylinder Oil	13.90
Painted Dull Black	14.40

VARIATION OF HEAT LOSS WITH PRESSURE

Pressure	Heat Loss B. T. U. per Sq. Ft. per Minute
340	15.97
200	13.84
100	8.92
80	8.04
60	7.00
40	5.74

A full account of some interesting tests can be found in a paper entitled *Protection of Steam-Heating Surfaces*, by C. L. Norton, Vol. XIX, Proceedings of the American Society of Mechanical Engineers, 1898, from which these tables have been taken.

Pipe Coverings. To make this loss from radiation as small as possible, it is customary to cover the pipe or boiler with some material which will prevent loss of heat and which will not burn. There is considerable difference in the value of various substances as preventatives of heat radiation. Their value varies nearly in an inverse ratio to their conducting power; but due allowance must be made for the possible deterioration of the pipe covering. The following table gives the relative value of various substances with reference to their ability to prevent radiation of heat. For purposes of comparison, the value of wool is taken as the standard:

RELATIVE VALUES OF VARIOUS PREVENTATIVES OF RADIATION OF HEAT

Felt, Hair, or Wool	100
Asbestos Sponge	98
Air-Cell Asbestos	89
Mineral Wool	68 – 83
Carbonate of Magnesia	67 – 76
Charcoal	63
Sawdust	61 – 68
Asbestos Paper	47
Wood	40 – 55
Asbestos, Fibrous	36
Plaster of Paris	34
Air Space (Undivided)	22

There are many patented coverings which are very efficient, but they are too numerous even to mention. The above-mentioned article from the Proceedings of the American Society of Mechanical Engineers gives the results of tests of several of these coverings. A good protection is afforded by air confined in minute cells, such as is to be had in the air-cell asbestos board; this is made by cementing together several layers of asbestos paper which have been corrugated or indented by machinery so as to form minute air-cells. The more minute the subdivision of these cells, the better the protection is likely to be. Hair felt is one of the most efficient non-conductors, because it is very porous and contains a large number of air-cells. It is not one of the best coverings, however, because it is liable to deteriorate, and its life on high-pressure pipes is not likely to be more than four or five years. On low-pressure work it may last for a considerably longer time.

Mineral wool, a fibrous material made from blast-furnace slag, is an efficient and noncombustible covering, but is brittle and liable to fall off.

The coverings most easily applied to pipes are those applied in sectional form, which clasp around the pipe and are fastened by brass bands at convenient intervals. Such coverings are made both of asbestos and of magnesia, and are usually of about 1 inch in thickness.

A good, cheap covering can be made by wrapping several layers of asbestos paper around the pipe, and then covering these layers with a layer of hair felt perhaps $\frac{3}{4}$ inch thick, the whole being wrapped in canvas. On low-pressure steam pipes this covering will last ten to fifteen years.

Cork is perhaps one of the most satisfactory coverings from the point of radiation loss, but is rather more expensive than asbestos or magnesia.

It has generally been the impression that it is not economical to cover a pipe to more than one inch in thickness. This will depend upon the cost of the covering and the length of time it is likely to last. If it does not last more than five years, one inch is probably the most economical thickness; but if the life of the covering is likely to be ten years or more, a second inch in thickness can be applied to advantage. For instance, in the above-mentioned tests, in the case of "Nonpareil cork," increasing the thickness from one to two inches raised the cost from $25 to $30 per 100 square feet, and increased the net saving in five years by $10, and by $30 in ten years. A third inch of covering did not produce saving enough to pay for its cost. In each case with the asbestos fire-board, a second inch in thickness showed a saving of $20 in ten years, while the third inch in thickness showed an actual loss from the dollars-and-cents point of view. It would be well to remark that it is of great importance that the pipe covering should be kept in repair, for a loose-fitting covering is of little value.

Boiler Coverings. Much the same remarks may be made with regard to boiler covering as have been made with regard to pipe covering, except that the covering put on boilers is usually somewhat less efficient and is applied in greater thickness. Probably one of the best coverings for a marine boiler—or, in fact, for any internally-fired boiler—is a layer of air-cell asbestos board, covered with a coating perhaps two inches thick of magnesia or asbestos. This comes in powder form, and when mixed with water can be readily applied with a trowel. Coverings on boilers are best placed directly against the shell without an air-space, so that any leak in a joint or rivet will reveal the spot by moistening the covering; otherwise the escaping water may run down through the air-space and appear at some remote point, the leak thus being difficult to locate.

An efficient covering for boilers is made of either magnesia or asbestos in the form of blocks of the proper curvature, which can lie directly against the boiler; but this form of covering is rather more expensive than the asbestos or magnesia cement. To secure an extra hard finish a coating of plaster of Paris may be put on outside the magnesia or asbestos. No boiler or pipe covering should contain sulphate of lime, as this is liable to cause corrosion.

If an internally-fired boiler is properly lagged, there is little danger that any large amount of heat will be lost, as the heat of the fire must pass through the water before radiating. This is not true with an externally-fired boiler, where a considerable amount of heat may radiate through the brick setting of the boiler without coming in contact with the boiler at all. The setting of such a boiler should be arranged with properly confined air-spaces; and an efficient protection from the radiation of heat at the top of the boiler may be had by allowing a slight space between the boiler and the top covering for the circulation of the hot gases of combustion. These are on their way to the chimney; and as they are necessarily hotter than the water in the boiler, they prevent radiation at this point.

HORSE-POWER OF BOILERS

The unit which we call the horse-power is *arbitrary*. Assuming that 30 pounds of steam are required per horse-power per hour for an average engine, this unit for boilers has been adopted.

One (1) horse-power is the evaporation of 30 pounds of water per hour, from a temperature of 100° F. into steam at 70 pounds gauge pressure. This is considered equivalent to the evaporation of $34\frac{1}{2}$ pounds per hour from and at 212° F. A boiler horse-power is equivalent to 33,327 B. T. U. per hour.

As all boilers do not generate steam at the same pressure and from the same temperature of feed-water, it is necessary to reduce the *actual* evaporation to an *equivalent* evaporation. Unless this is done, the relative performances of boilers cannot be compared.

For this comparison, the actual evaporation is reduced to the equivalent evaporation from and at 212° F. That is, we suppose the water to be fed at 212° and evaporated into steam at 212°.

Let W = Water actually evaporated in pounds;

H = Total heat of steam above 32° F., at actual absolute pressure;

T = Temperature of feed water;

w = Equivalent evaporation from and at 212° F.

Since 966 B. T. U. are necessary to evaporate one pound of water

FACTORS OF EVAPORATION

PRESSURE IN POUNDS PER SQUARE INCH ABOVE THE ATMOSPHERE (GAUGE PRESSURE.)

Temperature Feed-Water. Fahrenheit. Degr's	0	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	200	Temperature Feed-Water. Fahrenheit. Degr's
32	1.187	1.192	1.199	1.204	1.209	1.212	1.216	1.218	1.221	1.223	1.226	1.228	1.230	1.231	1.233	1.235	1.236	1.238	1.239	1.240	1.241	32
35	1.184	1.189	1.196	1.201	1.206	1.209	1.213	1.215	1.218	1.220	1.223	1.225	1.227	1.228	1.230	1.232	1.233	1.235	1.236	1.237	1.238	35
40	1.179	1.184	1.191	1.196	1.201	1.204	1.208	1.219	1.213	1.215	1.218	1.220	1.222	1.223	1.225	1.227	1.228	1.230	1.231	1.232	1.233	40
45	1.173	1.178	1.185	1.190	1.195	1.198	1.202	1.204	1.207	1.209	1.212	1.214	1.216	1.217	1.219	1.221	1.222	1.224	1.225	1.226	1.227	45
50	1.168	1.173	1.180	1.185	1.190	1.193	1.197	1.199	1.202	1.204	1.207	1.209	1.211	1.212	1.214	1.216	1.217	1.219	1.220	1.221	1.222	50
55	1.163	1.168	1.175	1.180	1.185	1.188	1.192	1.194	1.197	1.199	1.202	1.204	1.206	1.207	1.209	1.211	1.212	1.214	1.215	1.216	1.217	55
60	1.158	1.163	1.170	1.175	1.180	1.183	1.187	1.189	1.192	1.194	1.197	1.199	1.201	1.202	1.204	1.206	1.207	1.209	1.210	1.211	1.212	60
65	1.153	1.158	1.165	1.170	1.175	1.178	1.182	1.184	1.187	1.189	1.192	1.194	1.196	1.197	1.199	1.201	1.202	1.204	1.205	1.206	1.207	65
70	1.148	1.153	1.160	1.165	1.170	1.173	1.177	1.179	1.182	1.184	1.187	1.189	1.191	1.192	1.194	1.196	1.197	1.199	1.200	1.201	1.202	70
75	1.143	1.148	1.155	1.160	1.165	1.168	1.172	1.174	1.177	1.179	1.182	1.184	1.186	1.187	1.189	1.191	1.192	1.194	1.195	1.196	1.197	75
80	1.137	1.142	1.149	1.154	1.159	1.162	1.166	1.168	1.171	1.173	1.176	1.178	1.180	1.181	1.183	1.185	1.186	1.188	1.189	1.190	1.191	80
85	1.132	1.137	1.144	1.149	1.154	1.157	1.161	1.163	1.166	1.168	1.171	1.173	1.175	1.176	1.178	1.180	1.181	1.183	1.184	1.185	1.186	85
90	1.127	1.132	1.139	1.144	1.149	1.152	1.156	1.158	1.161	1.163	1.166	1.168	1.170	1.171	1.173	1.175	1.176	1.178	1.179	1.180	1.181	90
95	1.122	1.127	1.134	1.139	1.144	1.147	1.151	1.153	1.156	1.158	1.161	1.163	1.165	1.166	1.168	1.170	1.171	1.173	1.174	1.175	1.176	95
100	1.117	1.122	1.129	1.134	1.139	1.142	1.146	1.148	1.151	1.153	1.156	1.158	1.160	1.161	1.163	1.165	1.166	1.168	1.169	1.170	1.171	100
105	1.111	1.116	1.123	1.128	1.133	1.136	1.140	1.142	1.145	1.147	1.150	1.152	1.154	1.155	1.157	1.159	1.160	1.162	1.163	1.164	1.165	105
110	1.106	1.111	1.118	1.123	1.128	1.131	1.135	1.137	1.140	1.142	1.145	1.147	1.149	1.150	1.152	1.154	1.155	1.157	1.158	1.159	1.160	110
115	1.101	1.106	1.113	1.118	1.123	1.126	1.130	1.132	1.135	1.137	1.140	1.142	1.144	1.145	1.147	1.149	1.150	1.152	1.153	1.154	1.155	115
120	1.096	1.101	1.108	1.113	1.118	1.121	1.125	1.127	1.130	1.132	1.135	1.137	1.139	1.140	1.142	1.144	1.145	1.147	1.148	1.149	1.150	120
125	1.091	1.096	1.103	1.108	1.113	1.116	1.120	1.122	1.125	1.127	1.130	1.132	1.134	1.135	1.137	1.139	1.140	1.142	1.143	1.144	1.145	125
130	1.085	1.090	1.097	1.102	1.107	1.110	1.114	1.116	1.119	1.121	1.124	1.126	1.128	1.129	1.131	1.133	1.134	1.136	1.137	1.138	1.139	130
135	1.080	1.085	1.092	1.097	1.102	1.105	1.109	1.111	1.114	1.116	1.119	1.121	1.123	1.124	1.126	1.128	1.129	1.131	1.132	1.133	1.134	135
140	1.075	1.080	1.087	1.092	1.097	1.100	1.104	1.106	1.109	1.111	1.114	1.116	1.118	1.119	1.121	1.123	1.124	1.126	1.127	1.128	1.129	140
145	1.070	1.075	1.082	1.087	1.092	1.095	1.099	1.101	1.104	1.106	1.109	1.111	1.113	1.114	1.116	1.118	1.119	1.121	1.122	1.123	1.124	145
150	1.065	1.070	1.077	1.082	1.087	1.090	1.094	1.096	1.099	1.101	1.104	1.106	1.108	1.109	1.111	1.113	1.114	1.116	1.117	1.118	1.119	150
155	1.059	1.064	1.071	1.076	1.081	1.084	1.088	1.090	1.094	1.095	1.098	1.100	1.102	1.103	1.105	1.107	1.108	1.110	1.111	1.112	1.113	155
160	1.054	1.059	1.066	1.071	1.076	1.079	1.083	1.085	1.088	1.090	1.093	1.095	1.097	1.098	1.100	1.102	1.103	1.105	1.106	1.107	1.108	160
165	1.049	1.054	1.061	1.066	1.071	1.074	1.078	1.080	1.083	1.085	1.088	1.090	1.092	1.093	1.095	1.097	1.098	1.100	1.101	1.102	1.103	165
170	1.044	1.049	1.056	1.061	1.066	1.069	1.073	1.075	1.078	1.080	1.083	1.085	1.087	1.088	1.090	1.092	1.093	1.095	1.096	1.097	1.098	170
175	1.039	1.044	1.051	1.056	1.061	1.064	1.068	1.070	1.073	1.075	1.078	1.080	1.082	1.083	1.085	1.087	1.088	1.090	1.091	1.092	1.093	175
180	1.033	1.038	1.045	1.050	1.055	1.058	1.062	1.064	1.067	1.069	1.072	1.074	1.076	1.077	1.079	1.081	1.082	1.084	1.085	1.086	1.087	180
185	1.028	1.033	1.040	1.045	1.050	1.053	1.057	1.059	1.062	1.064	1.067	1.069	1.071	1.073	1.074	1.076	1.077	1.079	1.080	1.081	1.082	185
190	1.023	1.028	1.035	1.040	1.045	1.048	1.052	1.054	1.057	1.059	1.062	1.064	1.066	1.067	1.069	1.071	1.072	1.074	1.075	1.076	1.077	190
195	1.018	1.023	1.030	1.035	1.040	1.043	1.047	1.049	1.052	1.054	1.057	1.059	1.061	1.062	1.064	1.066	1.066	1.069	1.070	1.071	1.072	195
200	1.018	1.018	1.025	1.030	1.035	1.038	1.042	1.044	1.047	1.049	1.052	1.054	1.056	1.057	1.059	1.061	1.062	1.064	1.065	1.066	1.067	200
205	1.001	1.012	1.019	1.024	1.029	1.032	1.036	1.038	1.041	1.043	1.046	1.048	1.050	1.051	1.053	1.055	1.056	1.058	1.059	1.060	1.062	205
210	1.002	1.007	1.014	1.019	1.024	1.027	1.031	1.033	1.036	1.038	1.041	1.043	1.045	1.046	1.048	1.050	1.051	1.053	1.054	1.055	1.057	210
212	1.000	1.005	1.012	1.017	1.022	1.025	1.029	1.031	1.034	1.036	1.039	1.041	1.043	1.044	1.046	1.048	1.049	1.051	1.052	1.053	1.056	212

from and at 212° F., the equivalent evaporation may be found from the formula,

$$W\,(H + 32 - T) = 966w, \text{ or } w = \frac{W\,(H + 32 - T)}{966}.$$

Then the horse-power of the boiler is:

$$\text{H. P.} = \frac{w}{34.5}.$$

The above method is considerably shortened by substituting for the quantity $\frac{H + 32 - T}{966}$, the number found in the accompanying table (page 80) which corresponds to the actual feed-water temperature and steam pressure.

For example, a boiler is required to furnish 2,100 pounds of steam per hour. If the gauge pressure is 85 pounds, and the feed-water enters at 50° F., what is the equivalent evaporation, and what is the horse-power?

From the table, the factor for 85 pounds pressure and 50° F. is 1.204. Then the equivalent evaporation would be $1.204 \times 2{,}100 =$ 2,528.4 pounds; and $\frac{2{,}528.4}{34.5} = 73$ (approx.) = the H. P.

CORROSION AND INCRUSTATION

There are several causes which tend to shorten and destroy the life of every boiler. These may be divided into two general classes, chemical and mechanical, and are usually the result of improper feed-water or of improper care. Pure water, free from air and carbon dioxide, has no evil effect on the iron; but all natural waters, whether from rain, lake, river, or sea, contain air and a little carbon dioxide in solution, and such water will cause iron to corrode, even though no other impurities are present.

Sea water, heated under a steam pressure of 30 lbs., even if it contains no air, will liberate a small amount of hydrochloric acid, which instantly attacks the iron of the boiler unless counteracted by some chemical agent.

External Corrosion. There are two forms of corrosion, external and internal. External may be due to faulty setting, to improper care, or to moisture from external sources or from leakage from joints and valves. A large amount of external corrosion is the result of setting boilers in a mass of brickwork, which readily absorbs moisture, and which, when not under fire, is likely to keep the boiler-plates damp. The exterior of a boiler encased in brickwork, moreover, is not so easily accessible, and a considerable amount of deterioration may take place without being readily detected. The leakage from a joint, although slight, may, if long continued, badly corrode the boiler.

Internally-fired boilers are supported on saddles and are easily accessible; and the magnesia or asbestos lagging with which they are usually covered will tend to absorb a certain amount of moisture, which will be given off when hot, thus helping to keep the boiler dry. If a leak occurs of appreciable size, the covering will become softened and its presence will be detected at once, and repairs can be made before any serious damage is done. The exterior of an internally-fired boiler, being at all times accessible, can be properly taken care of, which is not true of a boiler set in brickwork. Rivets and riveted joints should as far as possible be kept out of contact with the fire.

Internal Corrosion. This is the result of the chemical action of impure feed-water. It may occur in the form of a general corrosion or wasting-away of the boiler-plates, or in the form of pitting or grooving, the effects of which are likely to be local. Pitting and general corrosion are entirely the result of chemical action, while grooving is the result of chemical and mechanical action combined.

It is not easy to discover general corrosion, because it acts more or less uniformly over a large surface. Sometimes the rivet-heads rust in proportion to the plates, so that the wasting-away of the plates is not easily noticeable. A uniform corrosion is the hardest to detect, and can usually be discovered only by drilling the boiler and gauging the thickness of the plate. If the thickness of the plate is found to be materially reduced, the working pressure of the boiler should be lowered in proportion.

Sometimes the water will attack the plates only in the vicinity of the water-line, in some instances confining the damage to a belt 6 inches or 8 inches wide. Sometimes a few rivets below water-level will be corroded, the rest remaining in a comparatively good condition. Often the stays are weakened more rapidly than the plates, and the screw-threads of a stay may be badly corroded while the shank of the stay remains uninjured.

Pitting. Fatty acids, which are likely to come over in the feed-water if vegetable oils are used to lubricate the cylinder, are especially active in the production of small pits throughout the interior of the boiler. Pitting appears in the form of small holes or in patches from $\frac{1}{4}$ inch to 1 inch in diameter, or even as irregularly shaped depressions. If the holes are small and close together, the plate is said to be *honey-combed.* It is generally believed that this phenomenon, the result of chemical action, is due to a lack of homogeneity in the material of the boiler, although an entirely satisfactory explanation has not yet been given. Pitting may also be caused by galvanic action, which may take place especially if sea water is used. As pitting occurs when there is no cause whatever for galvanic action, this can be only a secondary cause at best. It is reasonable to suppose that acids will attack the most susceptible portions of the plate; and if there is any lack of homogeneity in the iron, it is probable that the places or spots most favorable to chemical attack will suffer first.

Grooving. Grooving is probably the result of straining, springing, or buckling of the plates, aided by local corrosion or by the same forces which cause pitting. Straining of the plates may be due to insufficient or improper staying, thus causing the plates to spring back and forth as the steam pressure varies. This phenomenon is most commonly found in stationary boilers of the "Cornish" or "Lancashire" types appearing in the flat end-plates around the edge of the angle iron, or in the root of the angle iron. Too rigid staying of the ends by gussets or diagonal stays, or too great a difference in expansion between different parts, is almost sure to produce grooves.

Internal grooving may be caused as the direct result of excessive calking, which, by injuring the surface of the metal, exposes it to the corrosive action of the feed-water. It is to be expected that if strains which cause the plates to come and go are set up in the boiler—especially if the stresses can be concentrated along a definite line—a weakness will be developed there, and it will be a susceptible point for chemical attack. Sometimes grooving is so fine as to appear to be a mere crack. But the crack, although perhaps only $\frac{1}{64}$ inch in width, may extend into the plate for a considerable depth. Grooves are not readily detected, and if allowed to continue for any length of time are likely to produce serious results.

Prevention. The best way to prevent internal corrosion is to use water that has no corrosive effect on the plates. If internal corrosion has begun, a change of feed-water may prolong the life of the boiler, but in many instances it is cheaper to build a new boiler than frequently to change the water supply. Sometimes the introduction of a thicker plate at places where the water is found to be most active will be advisable; but, as these plates are stronger than the rest of the boiler, the strains will not be uniformly distributed, and stresses are likely to concentrate along the edge of this heavy plate, which will be a susceptible point for the formation of grooves.

The acidity of the feed-water may be neutralized by some alkaline substance, such as soda, before it enters the boiler. The amount of soda to be used varies with the acidity of the water; but it should always be used in the smallest possible quantity, as the soda is likely to produce priming in the boiler and will be injurious if there is much salt present. Vegetable oils should not be used for cylinder lubrication if the condensation is to be fed back to the boiler, as such oils contain acids which will always produce injurious effects. Mineral oils alone should be used.

To allow for a general corrosion, $\frac{1}{16}$ inch to $\frac{3}{16}$ inch extra thickness of shell should be provided. All seams of a boiler should be tight, and no welded tubes should be used, as pitting and grooving are likely to occur in the vicinity of the weld. When not in use, no moist air should be allowed in the boiler. A boiler can be thoroughly dried out either by the application of heat or by placing in it lime, which will readily absorb the moisture.

The water fed to the boiler should be thoroughly filtered to remove as much grease as possible, for, although mineral oil is not likely to cause pitting, it has a serious effect in the formation of boiler scale.

Incrustation. The incrustation formed by the accumulation of the deposit of sediment in the feed water, is called *scale* or *sludge.* The solid matter in the feed-water may be precipitated by the rise in temperature, or left behind as the result of the evaporation of the water. These solids, unless blown out, are liable to become hardened on the inner surface of the boiler. A thin coating of scale in itself is beneficial, for it keeps the water from direct contact with the iron, and prevents corrosion and pitting; but the danger is that if a thin scale forms, a thicker one will form, and this heavy scale, being a poor conductor of heat, not only causes considerable waste of fuel, but allows the plates next the furnace to become overheated, with the result that they are likely to give way, and the boiler may collapse.

The amount of solid matter in solution is measured in grains per U. S. gallon. The quantity varies greatly in waters from different sources, but is seldom over 40 grains per gallon. It is not the quantity of matter in solution, but its nature, that determines the influence of feed-water. With proper attention to the boiler, the presence of a certain amount of carbonate or sulphate of soda would not be injurious; while the same number of grains per gallon of salts of lime would cause serious trouble. Salts of lime (calcium), together with carbonate of magnesia, are the solids most frequently found, and are the most troublesome. *Hard water* contains considerable quantities of lime. So-called *soft water* has usually but little solid matter in suspension, but it may contain vegetable or organic impurities that will cause corrosion or pitting.

The oil used in the engine is likely to get into the boiler through the feed-water, if it is not carefully filtered or passed through a *grease-extractor*. The oil is likely to be deposited on the sides and tubes of the boiler, and not only is a poor conductor of heat, but, mingling with the sediment which is precipitated from the hot water, produces a mixture which is readily baked onto the boiler-plates and is especially obstinate and difficult to remove. There are efficient grease-extractors now on the market, which will remove practically every trace of oil.

Carbonate of Lime. Carbonate of lime is held in solution in water by an excess of carbon dioxide. As the water is heated, the excess of carbon dioxide, or carbonic acid, is driven off, and the carbonates will be precipitated in the form of a whitish or grayish sediment of the consistency of mud. If these precipitates are not mixed with impurities, they may be washed out of the boiler after it has been allowed to cool; but if there is oil, organic matter, or sulphate of lime, the deposits are likely to become hard. They may readily be drawn off through the bottom blow-out; but if there is much pressure in the boiler, the blow-out valve should be opened only for a very short time. If a considerable amount of water is blown out while the boiler is still very hot, a large part of this precipitation is likely to be baked onto the tubes and interior of the boiler in a manner that defies removal. Short and frequent blowings will accomplish the desired result; for while the boiler is in action these precipitates are more or less in motion, and frequent blowing will keep the boiler clear. Oil and various organic matters rising to the surface can easily be removed by frequently opening the surface blow-out.

Sulphate of Lime. This troublesome salt, like the carbonate of lime, is precipitated with a rise of temperature; and at 280° F., none is left in solution. This sediment is likely to form a hard, adhering scale; but if a little carbonate of soda, or soda ash, is introduced with the feed water, calcium carbonate is precipitated in the form of a white powder which can be readily washed out. The carbonate of soda should be introduced at regular intervals, a portion of it being dissolved in water which can be mixed with the feed in the hot well. As little soda as possible should be used, as it is likely to cause priming and foaming. The hardness of the scale formed by the sulphate of lime depends on the other impurities in the water and on the temperature; and consequently the amount of soda that can safely be used can be determined only by trial. Ammonium chloride, commonly called *sal-ammoniac,* is sometimes used to break up these lime compounds, but is not always desirable, as it may break up the chlorides if other conditions are right, thus forming free chlorine, which attacks the boiler.

Carbonate of Magnesia is seldom found in such large quantities as calcium salts. Like the carbonate of lime, it is precipitated in hot water. If there is any oil or organic matter present, it is likely to form an injurious precipitation.

Iron Salts form a reddish incrustation which is very injurious to boiler-plates. Brakish water containing chloride of magnesium is also injurious; for, when heated, the chloride decomposes, forming magnesia and hydrochloric acid, the latter rapidly corroding iron.

A piece of thick scale broken from the plates of the boiler, will show a series of layers of various thickness, some of them crystalline and some amorphous. Between these hard layers are frequently found layers of soft or earthy matter.

Nothing definite is known in regard to the loss of heat caused by scale on heating surfaces, for there are too many circumstances to be considered to admit of exact calculation. It has been stated that a layer $\frac{1}{16}$ inch thick in the tubes of multitubular boilers, is equivalent to a loss of from 15 to 20 per cent of fuel. The loss increases rapidly with the thickness of the scale. A uniform coating of scale is not nearly so harmful as irregular deposits, for in the latter case the evil effects of overheating are likely to be produced, and overheating will result where it is least suspected.

Prevention. Incrustation may be prevented by precipitating the scale-forming substances before the feed-water reaches the boiler, by the introduction of chemical compounds to neutralize the evil effects, or by removing the sediment before it becomes hard. Scale may, of course, be removed by hand from the interior of the boiler; but this is a slow and tedious process. One of the chief objections to removing scale by hand is that the surfaces of the boiler are likely to become abraded by the chipping tools, and this offers excellent opportunity for pitting and local corrosion to set in.

Scale has sometimes been removed by blowing the boiler off at comparatively high pressure, and then filling it with cold water. This causes a severe contraction of the plates, and is likely to loosen the scale; but it will at the same time cause serious injury to the boiler, and is a practice that should not be tolerated.

After the impurities are deposited in the boiler, they may be removed by the blow-out apparatus; and if it is possible to "lay off" the boiler occasionally, it should be allowed to cool down slowly, and then the water may be drawn off and the boiler properly washed out. A considerable amount of heat is abstracted from the boiler by frequent blowing-off, and this is a matter of direct loss, but it is nothing like so much as would be caused by the formation of scale.

Water may be purified to a certain extent by passing it through a *purifier* before allowing it to enter the boiler. The carbonate and sulphate of lime are precipitated at the same time that the water is heated. The purifier was referred to under the topic of "Feed-Water Heaters." The use of soda for the neutralization of sulphate of lime has already been spoken of; but various compounds are on the market for overcoming the evil effects of other solids; and it is possible, by an analysis of the feed water, to prescribe a boiler compound that will give satisfactory results. Cheap compounds, sold without reference to the analysis of the feed-water, should be avoided. Caustic soda may be used instead of the carbonate, but should be used in small quantities. A rapid circulation of the water will prevent the formation of scale, the sediment being swept from the tubes or shell into the mud-drum, whence it may be blown off. This is one of the chief advantages claimed for water-tube boilers.

Zinc plates have frequently been used to prevent corrosion and incrustation. The brass fittings are likely to set up a galvanic action with the steel plates; but if the zinc is put in, it will be acted upon instead of the iron, which otherwise might be rapidly wasted. It is claimed that this galvanic action prevents the formation of scale by liberating hydrogen at the exposed surfaces. The zinc neutralizes the free acids by combining with them, and takes the place of iron in causing precipitation of copper salts when present.

Kerosene oil is used to a considerable extent to prevent the formation of scale and to assist in its removal. It breaks up and loosens hard scale, and prevents its formation. About one quart a day is sufficient for each 100 horse-power of the boiler.

BOILER EXPLOSIONS

Safety is one of the first requisites in a steam boiler, and must be assured not only by proper design in the beginning, but by subsequent care and proper maintenance. The evil effects of corrosion and incrustation have been clearly shown; and it is apparent that a boiler which has suffered materially from either cause is not in condition to stand full steam pressure. Since the explosion of a boiler, especially in a city or a factory, is likely to prove fatal to many people and to cause the destruction of considerable property, not only by the explosion itself but also by fire, which almost invariably follows such an occurrence, it is impossible to lay too great emphasis on the necessity of seeing that the boiler is in proper working condition.

All boilers must be carefully tested—land boilers, by the State Inspectors; marine boilers, by the United States Inspectors. The boilers are carefully examined inside and outside, and subjected to a hydraulic pressure test 50 per cent greater than the designed pressure of steam; and if there is the slightest sign of pitting or corrosion, the boiler-plates may be drilled and the thickness calipered, the hole being refilled by a proper plug. If a boiler passes inspection, a subsequent explosion will probably be the result of mismanagement, although inspection is not infallible.

The owner of the boiler is usually held liable in case of explosion; but may protect himself from financial loss by insurance against accident in any of the boiler insurance companies. If so insured, the Insurance Inspector, as well as the State Inspector, examines the boiler; and there is consequently less likelihood of an explosion, for an insurance inspector will naturally be exceedingly careful in the interests of his company.

The damage done by an explosion is due to the energy stored in the hot water, which energy can be calculated by thermodynamic methods. If a boiler contains a large quantity of water at high pressure, and that pressure is suddenly relieved, as would happen in case of rupture, a considerable portion of this large volume of water will be turned instantly into steam, and the resulting explosion will ensue.

When a fracture starts in a boiler-plate, the steam escaping through the rent or opening tends to diminish the pressure rapidly within the boiler; and this causes the rapid formation of a large amount of steam. It must be remembered that the water in the boiler at high pressure is held in the form of water only because of the high pressure exerted on it. If this pressure is relieved, large quantities of water will evaporate into steam at once, without the application of further heat. This almost instantaneous formation of a large quantity of steam prevents the boiler pressure from dropping, and the fracture naturally widens. The larger the body of hot water, the greater the disaster. This accounts for the relative safety of water-tube boilers. The division of the water in such a boiler into small masses in different sections, prevents a violent explosion. Should a water tube burn out, probably nothing more serious would happen than the rapid escape of a considerable quantity of steam, which might fill the boiler-room, drive out the attendants, and ultimately cause the destruction of the boiler because of the absence of water together with a hot fire. It would be necessary for several water tubes to burst at once in order that there should be serious damage from such an accident.

Energy. The available energy in one pound of hot water at 150 lbs. absolute pressure and 358° F., is about 42,800 foot-pounds; that is, it is sufficient to move one pound nearly eight miles; and if at 250 lbs. pressure, it has sufficient energy to move it nearly twelve miles. This energy may be determined somewhat as follows: From the table of the properties of saturated steam, given in the back of the book, it is seen that at 150 lbs. absolute pressure (approximately 135 gauge), the temperature is 358.26° F. The heat contained in a pound of hot water at this temperature will be 330 B. T. U., equivalent to 330 × 778 = 256,740 foot-pounds. This represents the total heat energy in one pound of hot water at boiler pressure; but since one pound of steam at atmospheric pressure contains very many more heat units than a pound of water at 150 lbs. pressure, it is apparent that only a portion of this water can evaporate into steam, the balance remaining as hot water. About 17 per cent of the total energy will be thus available in vaporizing the water into steam; or, approximately, 42,800 foot-pounds per pound of water will be developed. The remaining heat is in the form of hot water.

A cylindrical boiler 5 feet in diameter and 16 feet long is likely to contain about 6,600 pounds of water and 22 pounds of steam. Neglecting the energy of the steam, which is relatively small, the energy in the water due to its expansion from water at boiler pressure into steam at atmospheric pressure, will be approximately 6,600 × 42,800 = 282,480,000 foot-pounds, or 141,240 foot-tons.

A marine boiler 13 feet in diameter and 12 feet long would develop approximately twice this energy, which would be about equivalent to the energy developed by the explosion of a ton of gunpowder. The explosion of one boiler on a modern battleship would develop sufficient power to lift the ship completely out of the water. Of course it must be realized that a large part of this energy is lost, and considerable is consumed in the destruction of the boiler itself, which leaves but a comparatively small amount to be expended in wrecking the immediate surroundings; but it nevertheless is a fact that the energy developed in the explosion of a large boiler is almost beyond the power of comprehension.

Causes of Explosions. Boiler explosions are usually the result of low water, grease, or scale. The two latter, by preventing the transmission of heat from the water, are likely to cause undue overheating of the furnaces or tubes, which may result in their collapse; these two causes—grease and scale—have been discussed under the subject of "Incrustation."

Low water may be caused by failure of the water glass to indicate properly the amount of water in the boiler, or by failure of the feed pump to work properly.

Safety-valves have been known to be rusted to their seats so tightly that they failed to work at the proper time.

It is seldom that a boiler can fail as the result of defective design, for the laws in regard to construction, especially of marine boilers, are very definite. Defective workmanship or material, however, cannot be easily discovered; and it is possible that corrosion or incrustation may take place locally, without being readily detected; and, indeed, boiler-plates may even be tapped, and their thickness calipered, without discovering small local weaknesses which later may cause disaster. Minute fractures which escaped the Inspector's detection have later become serious. The majority of explosions can undoubtedly be traced to mismanagement in either care or operation.

Defective Design. If a boiler is improperly set; if the stays are too small, too few, or cut or bent to clear floats, pipes, etc., danger is likely to result therefrom. All manholes, large handholes, or domes should be strengthened with a reinforcing plate to make up for the material cut out. If the boiler is set too rigidly on its seating, without proper provision for its expansion, trouble is likely to follow. A defective water circulation is likely to cause excessive incrustation and unequal expansion of the plating, which is liable to open seams and produce fractures in the plates.

Deterioration. The strength of a boiler is likely to be impaired by fractures, general corrosion, pitting, or grooving. But external corrosion is the cause of many disasters. It proceeds unnoticed in many cases, and rupture may occur when least expected. In the discussion of "Corrosion," it was shown that improper setting of the boiler would cause or at least aggravate external corrosion; and that, on account of the close setting of the boiler, it was not easy to get at the plates to examine them. The strength of a boiler originally sufficient to sustain high pressure may become suddenly reduced by overheating or over-straining, either of which weakens the plates. Overheating may be caused by poor circulation, lack of water, or the accumulation of sediment or scale. Over-straining is caused by sudden cooling and contraction, or equally by sudden expansion. In starting the fire in a Scotch boiler—or, in fact, in any boiler with a large quantity of water—care must be taken that the fire is started slowly, or the boiler, becoming overheated locally, will develop excessive strains.

Defects of Workmanship. Defective workmanship is not of so frequent occurrence under present conditions as formerly, when many defects used to be produced by careless punching of plates; but for most boilers, and for all marine boilers at present, punching is prohibited; the holes must be drilled, and the plate edges planed and carefully calked. A rigid inspection of material is required, and there seems little danger of unsatisfactory work. Cheap boilers may of course be subject to various defects, but a good boiler should be free from such troubles. Material may be defective and may not be readily detected; but the careful tests now required, especially in marine work, reduce these possibilities to a minimum.

Mismanagement. The pressure in a steam boiler may rise above that at which the safety-valve has been set to operate, because of corrosion or overloading of the valve. Stop-valves are sometimes placed between the boiler and the safety-valve; but this practice should be condemned, as it is possible that the stop-valve may be closed when the fireman thinks the safety-valve is open to the boiler pressure. If the size or lift of the safety-valve is too small, steam may be generated faster than it can escape, in which case the pressure will rise in spite of the safety-valve. It has been claimed that the blowing-off of the safety-valve when the boiler is under excessive pressure may be the cause of starting an explosion; but the reason why this should be so does not seem to be especially clear, and it seems to be improbable if the opening of the safety-valve is sufficient to cause a reduction in pressure. Safety-valves have sometimes been loaded down temporarily to prevent leakage at working pressure; but such a practice is little short of criminal. If a safety-valve leaks, it should be reground, but under no circumstances should the weight on the lever be altered.

It is a common idea that when the furnace plates become very hot, perhaps heated to redness, due to a lack of water, and the feed is turned on, a violent explosion is sure to follow. Experiments show that when a piece of wrought iron is heated to redness and plunged into a weight of water three or four times greater than that of the iron, a comparatively small quantity of steam is disengaged. There is no reason to believe that this quantity would be greater if the iron were in the form of a boiler than in the form of a plate. If a small quantity of water were admitted to hot plates, the danger would be greater; and while a boiler under this condition might explode, the comparatively small quantity of water in it would make the resulting danger much less than if the boiler were under working conditions.

The following experiments illustrate the action of cold water on hot plates. A boiler 25 feet long and 6 feet in diameter was heated red hot and the feed turned on. No explosion occurred; but the sudden contraction of the overheated plates caused the water to pour out in streams at every seam and rivet-hole as far as the fire-mark extended. In another instance, the water was almost entirely drawn off while the fires were burning briskly. When the remaining water had been converted into steam and all the fusible plugs melted out, water at the rate of 28 gallons per minute in a series of fine jets was played on the hot plates. Such treatment may ruin a boiler for further service, though the boiler may not explode.

That a tough paper or cloth is easily torn when once a tear is started, is a well-known fact. Similarly a boiler-plate may be ruptured at slight pressure if a fracture has been started.

The *position of the fracture* or hole has a great influence on the results. In case a large rent occurs at the top of a cylindrical boiler, the steam and hot water may blow out of the hole; and the boiler, if strongly enough seated to stand the reaction, will remain on its seat. The damage to the boiler would be slight. But suppose the same rent were situated on the under side of the boiler near the ground or floor; the effect would be very different, the reaction of the escaping steam would probably blow the whole boiler through the roof.

Investigation. When an explosion occurs, it should be *investigated,* not only to fix the responsibility where it belongs, but also to provide for and take means to prevent future disasters. It has been customary to attribute all explosions to low water, since it is an easy way to throw the responsibility from the makers or owners upon the fireman, who, even if living, cannot defend himself. In the investigation of an explosion, the weights, shapes, positions, and directions of the scattered pieces should be noted, so that their original places may be known. The original size and shape of the boiler and of the fittings should be known as accurately as possible. The primary rent may be discovered from comparison and from deductions of the directions taken by the heavier pieces. Light pieces will generally take the direction of the escaping steam, while the heavy parts take an opposite direction, that of the reaction. A careful examination of the pieces, noting the age of fractures, thickness of plates, amount of corrosion, condition of plates, etc., will generally show the cause. A test of the plates will in many cases show any softening or yielding to the pressure and excessive thinness caused by bulging.

Prevention. The means taken to prevent boiler explosions from most of the above-mentioned causes, have already been given. It is of primary importance that at the start only a well-designed and well-made boiler should be used. The matter of type is not of so much importance; but it is well to use a sectional boiler in large cities or in buildings where many people are employed. There are many methods, some of which have been discussed, that are taken to prevent deterioration by corrosion, fracture, etc. Proper setting is of great importance in this matter. Mishaps from mismanagement may be greatly lessened by the employment of licensed attendants. A boiler should *never* be in the hands of a man who is not thoroughly competent to run it. The most effective method to prevent explosions is the law of the State, compelling regular, thorough inspection and licensed firemen. The inspection by the Boiler Insurance companies is also an efficient method.

During a period of eleven and one-half years, 70,000 boilers were inspected by Boiler Insurance companies. It was estimated that there were 140,000 in use during that time. Of the inspected boilers, there were 23 explosions and 50 collapses, resulting in 27 deaths from explosions, and 28 deaths from collapses. The explosion rate was 1 in 11,000; and the death rate, 1 in 14,600. The uninsured boilers did not make so good a showing, the death rate being 1 in 5,000 boilers, or about 3 times as high as among the insured boilers.

FUEL

There are various kinds of fuel used in steam production, location, cost, and the exigencies of the case being the deciding factors. Usually the kind of fuel is determined upon, and the boiler designed with that end in view. Sometimes, however, the fuel must be adapted to the boiler.

Coal. Coal is not only the most important fuel, but in many localities the only one available. It is of vegetable origin, being the long-decayed product of ancient forests. Frequently it occurs so mixed with earthy matter as to be of little value; but the supply of good coal is still abundant, and likely to be so for some time to come.

The most important elements in coal are hydrogen, producing 62,000 B. T. U. per pound, and carbon, producing 14,500 B. T. U. per pound. Although several coals may have the same total percentage of combustible material and ash, the heat values may not be the same, because heat value depends upon the amounts of hydrogen and carbon they contain. The heat value of fuels is determined by chemical analysis, or by calorimetric test, and varies for coal from different localities. The following table is compiled from several sources:

ANALYSIS AND HEAT VALUE OF VARIOUS COALS

Kind of Coal	Per cent of Ash	Theoretical B. T. U. per Pound	Pounds of Water Evaporated per Pound (Theoretical)
Penn. Anthracite	3.49	14,199	14.70
Penn. Anthracite	2.90	14,221	14.72
Penn. Cannel	15.02	13,143	13.60
Penn. Connellsville	6.50	13,368	13.84
Penn. Semi-bituminous	10.70	13,155	13.62
Penn. Brown	9.50	12,324	12.75
Kentucky Caking	2.75	14,391	14.89
Kentucky Cannel	2.00	15,198	16.76
Kentucky Lignite	7.00	9,326	9.65
Indiana Caking	5.66	14,146	14.64
Indiana Cannel	6.00	13,097	13.56
Maryland Cumberland	13.88	12,226	12.65
Arkansas Lignite	5.00	9,215	9.54
Colorado Lignite	9.25	13,562	14.04
Texas Lignite	4.50	12,962	13.41
Washington Lignite	3.40	11,551	11.96

In practice, no fuel gives its theoretical evaporation value. On account of several losses that are inevitably incurred, heat is radiated from, and conducted away by, the boiler setting. The admission of too much air into the furnace, either through the doors or through cracks in the setting, reduces the theoretical evaporation value. Improper firing causes considerable loss; and errors in design, construction, or setting reduce the efficiency.

The different kinds of coal are too numerous to be easily named, but in general they may be classified as *anthracite* or *bituminous*, commonly called *hard* or *soft* respectively, of which there are various subdivisions.

Anthracite. Anthracite coal consists almost entirely of carbon, but has a small amount of hydrocarbon. Good anthracite is lustrous, hard, flinty, but breaks up easily under high temperature. It burns with very little flame and smoke, and gives an intense heat. It does not ignite so readily as the softer varieties of coal; but once started, the fire requires less attention. It is an excellent fuel where the production of smoke is a decided objection.

Semi-Anthracite. This is a coal between pure anthracite and semi-bituminous. It is not so hard as anthracite, and burns more freely. It is not so compact as anthracite, and burns with a short flame, the anthracite having practically no flame.

Semi-Bituminous. This is the next softer grade of coal. It burns more freely than either anthracite or semi-anthracite, contains more volatile hydrocarbon, and is a valuable coal for steaming purposes.

Bituminous. Bituminous coal forms by far the larger portion of steam coal. It contains a large but varying amount of hyrocarbon or bituminous matter. Unless fired with care, it will produce a considerable amount of smoke and clinkers.

Dry Bituminous. This is a black coal with a resinous luster. It burns freely, and kindles with much less difficulty than the anthracites. It is hard, but is easily splintered. When burning, it gives a moderate amount of flame, with but little smoke, and does not cake. It is found chiefly in Maryland and Virginia.

Caking Bituminous. This contains less carbon and more hydrocarbon than the former class. It is not so black; is more resinous; and, under intense heat, readily forms into a solid, pasty mass. Unless frequently broken up, this pasty mass forms a blanket over the grate, and checks the draft. Caking bituminous is a valuable coal for the manufacture of gas. It is mined chiefly in the Mississippi valley.

Cannel. *Cannel* or *long-flame bituminous* coal produces a considerable quantity of smoke. It is mined chiefly in Pennsylvania, Indiana, and Missouri; and is a free-burning coal, with a strong tendency to cake. It is largely used for open-grate purposes.

Lignite. *Lignite,* or *brown coal* is intermediate between coal and peat. It is made up mostly of carbon, with some moisture and mineral matter. Poor varieties are of little value. Good lignite kindles with ease, and burns freely, but is likely to contain a considerable amount of water, and unless kept in a dry place will absorb moisture. It is not a very good fuel, but is used in some localities where other varieties are more expensive. It comes largely from Colorado, Texas, and Washington.

Peat. This is a form of fuel consisting of decayed roots, tree-trunks, etc., and earthy matter. It is found in swamps and bogs, and has been in process of decomposition a much shorter time than any of the coals. It is cut out in blocks and dried. Peat has a specific gravity of .4 to .5, but it can be compressed to a much greater density. It is necessary that peat should be kept in a dry place, for it will readily absorb moisture.

Coke. This is made by driving off by heat the hydrocarbon of bituminous or semi-bituminous coals. It may be made in gas retorts, as a by-product of gas production; or it may be made in coking ovens, the gas being the by-product. The latter form of coke is more valuable as a fuel. If the coal is very moist, or if steam is used in the coking process, as in the manufacture of water gas, the sulphur is burned out. Coke burns without flame; and, with a free supply of air, will make an intensely hot fire.

Charcoal. Charcoal is practically never used for steam fuel, its chief use being for household or manufacturing purposes. It is made by evaporating the volatile matter from wood, either by partial combustion or by heating in retorts. About 50 bushels of charcoal can be obtained from a cord of wood.

Culm. This is a name given to refuse dust at the coal mines, sometimes called *slack*. It can be bought at the mines at a very low rate; but the cost of transportation prohibits its use except in the immediate vicinity of the mines. On account of its fineness, it cannot be burned in an ordinary grate, and is usually blown into the boiler with a sufficient quantity of air, where it burns somewhat like a gas. A grate beneath usually contains a moderate fire, which keeps the culm well ignited and prevents the loss of any particles that might otherwise drop out of the furnace.

Wood. There are two principal divisions of wood—*hardwood*, which is compact and comparatively heavy, such as oak, ash, and hickory; and *soft wood,* which is of soft and porous texture and of less specific gravity, such as pine, birch, and poplar. Wood contains considerable moisture, even if left to season in a dry place; and after being thoroughly dried, it will absorb and retain from 10 to 20 per cent of moisture. Kiln-dried wood contains nearly 8,000 B. T. U. per pound, while the average wood, containing about 25 per cent of moisture, has a heating value of about 6,000 B. T. U.

The chemical composition of different woods is nearly the same, and pound for pound one class of wood contains about the same heating value as another. Pine weighs about half as much as oak per cubic foot, and a cord of such wood contains about half the heating value that a cord of oak would contain.

Sawdust and *shavings* are frequently used as fuel in sawmills and planing mills. This kind of fuel is blown into the furnace with air from a fan, and makes an intense heat. A fine grate at the bottom collects the burning embers, which might otherwise drop into the ash-pan. In mills where sawdust and shavings are used, they are a by-product.

Straw. Threshing machines through the West use straw almost entirely for fuel. It gives an intense heat, furnishing 5,000 to 6,000 heat units per pound; and this is a quick and easy way to get rid of it.

Bagasse is the fibrous portion of the sugar-cane left after the juice has been extracted. In the modern process of sugar manufacture, the cane is pressed so tightly that it is ready for fuel without further treating. Under favorable conditions it forms an excellent fuel. The pressed cane is a by-product which must in some way be got rid of. It is usually fed into the furnace through an automatic hopper; or it may be dumped in the fire-room and fed into the furnace by hand. The furnace is constructed of brick, independent of the boilers; and when bagasse is consumed at a high temperature, the oxygen contained in it is nearly sufficient to satisfy the carbon and hydrogen, so that little air from the outside is required. Such material, of course, cannot be fed into an ordinary furnace.

Liquid Fuels. These consist of petroleum and its products, and their use has become quite extensive in the last few years. The field would undoubtedly be wider were there less difficulty in obtaining a regular and constant supply. The greatest quantities of petroleum oil are produced in the United States and Russia. Large quantities are found on the Pacific Coast, especially in Southern California; and in that section of the country, oil is used as fuel to a greater extent than in the East, being largely used on tugboats, ferryboats, and locomotives.

The following, approximately, is the composition of petroleum:

Carbon	82 to 87 per cent.
Hydrogen	11 to 15 per cent.
Oxygen	$\frac{5}{10}$ to 6 per cent.

The theoretical heating power of petroleum is approximately 20,000 B. T. U. per pound, which is nearly half as much again as that of good coal. Oil has a further advantage over coal, in that no unburned fuel necessarily passes through the furnace, and there is no ash—an important item in marine work.

The composition and specific gravity of petroleums vary considerably, many of the lower grades being unsafe on account of their low flash-point.

The fuel is fed into the furnace through an atomizer operated either by steam or by compressed air. Several types of such devices are shown in Fig. 72. The use of the oil as a fuel can be readily controlled by the simple manipulation of a valve; and if the fire is once regulated to produce the required heat, it can be kept at that point with very little care. The fire can be started with slight trouble, and can be extinguished instantly. The vaporizing efficiency of oil is much greater than that of coal; and on the Pacific Coast, where oil can be readily obtained, it is a much more economical fuel. If burned properly, without too heavy an air-blast, there should be no production of smoke. A considerable saving may be effected in the

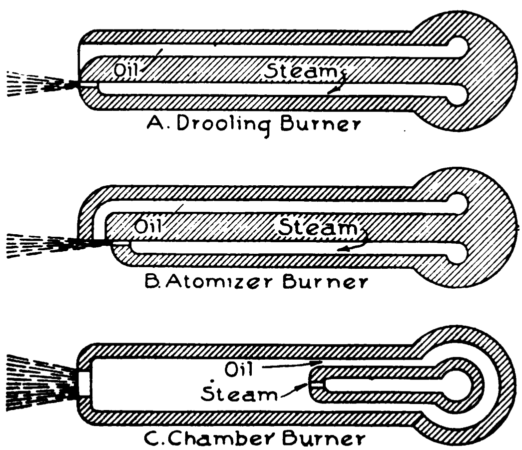


Fig. 72. Types of Atomizers for Liquid Fuel.

fire-room force, one man being able to operate several burners. There is, of course, danger from explosion, on account of vapor which rises from the fuel; but if the fuel tank is thoroughly ventilated, there is little danger from this source.

Oil fuel may be used to advantage in what is called *mixed firing*; that is, the oil may be sprayed onto the bed of burning coal. This has been condemned by many engineers, but it has nevertheless gained considerable headway, and, under proper conditions, has given satisfactory results. It is beyond the scope of this work to go minutely into the subject of oil fuel; but for further information the student is referred to the reports of the Oil Fuel Boards of the U. S. Navy and of the British Admiralty.

Gas. Gas has many advantages over any other kind of fuel. There are four different varieties—*natural gas, coal gas, water gas,* and *producer gas*. *Natural gas* is used largely in the vicinity of Pittsburg, Buffalo, and some parts of Indiana, both for illuminating and for steam purposes. Where natural gas is plentiful, it is by far the cheapest fuel that can be used.

Coal gas, made by the distillation of coal, and *water gas,* obtained by the decomposition of steam by incandescent carbon, have been used both for lighting and for fuel; but in most cases these gases may be used to greater economy directly in the cylinder of a gas engine than as fuel under a steam boiler. The same may be said of *producer gas,* which is made by blowing steam and air through incandescent coal.

The relative values of these gases for evaporation, are shown in the following table:

EVAPORATIVE POWER OF GASES

	Natural Gas	Coal Gas	Water Gas	Producer Gas
Cubic feet of gas	1,000	1,000	1,000	1,000
Pounds of water evaporated	893	591	262	115

Experiments in Pittsburg have shown that 1,000 cubic feet of natural gas equals 80 to 133 pounds of coal. The coal used in the comparison varied from 12,000 to 13,000 B. T. U. per pound.

The Western Society of Engineers has stated that one pound of good coal is equivalent in heating value to 7½ cu. ft. of natural gas.

As in the case of petroleum, the economy of burning gaseous fuels depends upon the locality.

Artificial Fuels. The waste of charcoal, coal, sawdust, etc., is often pressed into cakes or *briquettes*, by means of some adhesive mixture, with compression. Wood tar, coal tar, and clay are used, according to convenience. These cakes are compact, can be stored in small space, and are used where good fuels are difficult to obtain.

STEAM BOILER TRIALS

The object of a boiler trial is to determine the quantity and quality of steam that the boiler will supply under given conditions, the horse-power of the boiler, the amount of fuel it takes to make the required steam, and its efficiency.

The quantity of steam is taken as the amount of water evaporated, which, of course, is the total amount fed into the boiler during the test the water-level being the same at the beginning and the end.

The quality of the steam can be determined by some form of calorimeter already described; and the efficiency is the ratio of the heat units utilized in evaporating the water to the total heat supplied to the boiler. The heat utilized in evaporation can be found by multiplying the number of pounds of feed-water by the number of heat units required to change the water at the temperature of the feed into steam at gauge pressure. The heat units supplied can be determined by carefully weighing the fuel used during the test, and deducting the amount of ash and unburned fuel going through the grates, with proper allowance for moisture, multiplying the result by the total heat of combustion of the fuel. The heat of combustion can be obtained by calculation, or by means of a fuel calorimeter.

Under a short test the boiler must be in good working order and fired for some hours before the beginning of the test, so that the brickwork and chimney may be thoroughly heated. Shortly before the test is begun, the fire may be allowed to burn low; and by reducing the amount of steam taken from the boiler, the pressure can be kept constant. The fire may then be drawn, the grate cleaned, and a new fire quickly started, with wood and fresh coal. Toward the end of the test the fire may be allowed to burn low, and at the close may be drawn and quenched with water, the unburned fuel being allowed for. In a long test of twenty-four hours or more, this is not necessary.

If the boiler is fed by a steam pump, the pump should be run by steam taken from some other boiler, if convenient; if not, the amount of steam used by the pump must be determined and allowed for. If the feed-water is supplied by an injector, it will take steam from the boiler itself. About 2 per cent of this steam is consumed in forcing the water into the boiler, the remainder going to heat the feed-water.

During the boiler trial, observations of temperatures and pressures should be made at the same time, and at about 15-minute intervals. In order to obtain the result of the test, the following must be known:

1. Amount (in pounds) of coal burned, and number of pounds of ashes left;
2. Number of pounds of water pumped into boiler;
3. Temperature of feed-water when it enters boiler;
4. Pressure of steam in boiler;
5. Quality of steam discharged from boiler—that is, the per cent of moisture in the steam.

The coal for the furnace can be conveniently weighed in barrels, and may be fired directly from these barrels or dumped on the fire-room floor. The barrels should be carefully weighed when full and empty, and the time recorded, so that there may be no possibility of counting one barrel twice or omitting any. The rate of combustion will be fairly uniform, and the calculations at the times of emptying the barrel will fairly indicate whether or not an error has been made. Any unburned coal should be weighed, and the amount subtracted.

The condition of the fire for a twenty-four-hour test should be the same at the beginning and the end. This condition is estimated by the eye; and unless great care is used, an appreciable error is likely to be made If the coal consumption is 15 to 20 lbs. per square foot of grate surface, an error of two inches in estimating the thickness of the fire may cause an error of as much as 2 per cent in the final results.

The wood used in starting the fire should be carefully weighed, and may be considered as equal to $\frac{4}{10}$ of the same weight of coal. The clinker and ashes should be carefully collected and weighed, and a sample of the ashes examined to obtain the amount of unburned fuel.

There are several ways of determining the amount of water pumped into the boiler. The best method is to weigh it in tanks or barrels set upon standard scales. There should be two or more barrels of sufficient size, so that the filling and emptying may not be hurried. They should be set high enough to discharge readily into the tank or hot well from which the feed-water is drawn. The valves should be large and should open quickly, so that the emptying may not be delayed. If barrels are used, they should be numbered, and the weight of each accurately noted, so that there may be no mistake in deducting the weight of a barrel from the total weight of barrel and water. When one barrel is being emptied, the other may be filled. The weigher must use care and intelligence; otherwise he may become confused in his records, as in a boiler of considerable size the barrels fill and empty rapidly. At the beginning of the test, the level of the water in the hot well should be recorded, and at the end of the test should be brought to the same mark. If inconvenient to weigh the water, it may be measured by a meter; but if a meter is used, it should be tested and its error determined under like conditions of temperature and pressure. The feed-water should be free from air, as otherwise too large a meter reading will be recorded.

The level in the water-glass of the boiler should be carefully noted at the beginning and end of the test. If possible, the level should be constant throughout the test; and if there is any difference between the beginning and the end, due allowance should be made for it.

The temperature of the feed-water can be taken best by means of a thermometer in a cup filled with oil screwed into the feed-pipe near the check-valve. If the temperature is nearly constant, readings at 15-minute intervals will suffice; otherwise readings should be taken every five minutes.

The steam pressure shown by the gauge should be as nearly constant as possible throughout the test, and should be practically the same both at the beginning and at the end. Gauge readings should be recorded every 15 minutes, and the fireman should see that the pressure is constant. The gauge should be tested, and corrected if necessary.

Barometric readings should also be taken, two or three being sufficient for a ten-hour run. These readings, in inches, may be made to indicate pounds pressure by multiplying by .491, this being the weight of one cubic inch of mercury. If the trial is on a vertical boiler which furnishes superheated steam because of the heat being in contact with the tubes above the water-level, both the pressure-gauge and the thermometer should be used, so that the amount of superheating can readily be found by subtracting the temperature due to pressure (obtained from the steam tables) from the temperature readings.

The quality of steam can readily be determined by a calorimeter. If there is sufficient steam space within the boiler, from 1 to 2 per cent priming will generally result. If the steam space is inadequate, there will be more priming. If more than 2 per cent priming is present, the steam will blow white from the gauge-cocks when opened; if less than 2 per cent, it will appear blue.

The above observations are of the more important class, and *must* be taken. In addition to these, it is well to take samples of the flue gas at intervals and from various places in the furnace or chimney, the object being to determine whether there is a sufficient supply of air admitted, or whether there is too much. The draft of the chimney may be measured by means of a U-tube partially filled with water, or by a draft-gauge.

It is well to bear in mind that in making the boiler test the utmost care must be used, both in taking observations and in recording them, and in working up the results of the trial. A committee of the American Society of Mechanical Engineers has recommended a code of rules for boiler trials, and the following standard form for recording results. These are too voluminous for complete reproduction, and they can be found in full in Vol. XXI of the *Proceedings* of the above Society for the year 1900. The following code of rules is practically an abstract of the above-mentioned code:

PRELIMINARIES TO A TEST

1. In preparing for and conducting trials of steam boilers, the specific object of the proposed trial should be clearly defined and steadily kept in view.

2. Measure and record the dimensions, position, etc., of grate and heating surfaces, flues, and chimneys; proportion of air-space in the grate-surface; kind of draught, natural or forced.

3. Put the boiler in good condition. Have heating surface clean inside and out; grate-bars and sides of furnace free from clinkers; dust and ashes removed from back connections; leaks in masonry stopped; and all obstructions to draught removed. See that the damper will open to full extent, and that it may be closed when desired.

Test for leaks in masonry by firing a little smoky fuel and immediately closing damper. The smoke will escape through the leaks if there be such.

4. Have an understanding with the parties in whose interest the test is to be made, as to the character of the coal to be used. The coal must be dry; or, if wet, a sample must be dried carefully, and a determination of the amount of moisture in the coal must be made, the calculation of the results of the test being corrected accordingly. Wherever possible, the test should be made with standard coal of a known quality. For that portion of the country east of the Alleghany mountains, good anthracite egg coal or Cumberland semi-bituminous coal may be taken as the standard for making tests. West of the Alleghany mountains and east of the Missouri river, Pittsburg lump coal may be used.

In all important tests, a sample of coal should be selected for chemical analysis.

5. Establish the correctness of all apparatus used in the test for weighing and measuring. These are: *1.* Scales for weighing coal, ashes, and water. *2.* Tanks or water-meters for measuring water. Water-meters, as a rule, should only be used as a check on other measurements. For accurate work the water should be weighed or measured in a tank. *3.* Thermometers and pyrometers for taking temperatures of air, steam, feed-water, waste gases, etc. *4.* Pressure-gauges, draft-gauges, etc.

6. Before beginning a test, the boiler and chimney should be thoroughly heated to their usual working temperature. If the boiler is new, it should be in continuous use at least a week before testing, so as to dry the mortar thoroughly and heat the walls.

7. Before beginning a test, the boiler and connections should be free from leaks; and all water connections, including blow and extra feed-pipes, should be disconnected or stopped with blank flanges, except the particular pipe through which water is to be fed to the boiler during the trial. In locations where the reliability of the power is so important that an extra feed-pipe must be kept in position, and in general when, for any other reason, water-pipes other than the feed-pipes cannot be disconnected, such pipes may be drilled so as to leave openings in their lower sides, which should be kept open throughout the test as a means of detecting leaks or accidental or unauthorized

opening of valves. During the test the blow-off pipe should remain exposed.

If an injector is used it must receive steam directly from the boiler being tested, and not from a steam-pipe or from any other boiler.

See that the steam pipe is so arranged that water of condensation cannot run back into the boiler. If the steam pipe has such an inclination that the water of condensation from any portion of the steam-pipe system may run back into the boiler, it must be trapped so as to prevent this water getting into the boiler without being measured.

8. A test should last at least ten hours of continuous running, and twenty-four hours whenever practicable.

9. The conditions of the boiler and furnace in all respects should be, as nearly as possible, the same at the end as at the beginning of the test. The steam pressure should be the same, the water-level the same, the fire upon the grates should be the same in quantity and condition, and the walls, flues, etc., should be of the same temperature. To secure as near an approximation to exact uniformity as possible in conditions of the fire and in temperatures of the walls and flues, the following method of starting and stopping a test should be adopted.

10. **Standard Method.** Steam being raised to the working pressure, remove rapidly all the fire from the grate, close the damper, clean the ash-pit, and as quickly as possible start a new fire with weighed wood and coal, noting the time of starting the test and the height of the water-level while the water is in a quiescent state, just before lighting the fire.

At the end of the test, remove the whole fire, clean the grates and ash-pit, and note the water-level when the water is in a quiescent state; record the time of hauling the fire as the end of the test. The water-level should be as nearly as possible the same as at the beginning of the test. If it is not the same, a correction should be made by computation, and not by operating pump after test is completed. It wil generally be necessary for a time to regulate the discharge of steam from the boiler tested, by means of the stop-valve, while fires are being hauled at the beginning and at the end of the test, in order to keep the steam pressure in the boiler at those times up to the average during the test.

11. **Alternate Method.** Instead of the Standard method above

described, the following may be employed where local conditions render it necessary:

At the regular time for slicing and cleaning fires, have them burned rather low, as is usual before cleaning, and then thoroughly cleaned; note the amount of coal left on the grate as nearly as it can be estimated; note the pressure of steam and the height of the water-level—which should be at the medium height to be carried throughout the test—at the same time; and note this time as the time of starting the test. Fresh coal, which has been weighed, should now be fired. The ash-pits should be thoroughly cleaned at once after starting. Before the end of the test the fires should be burned low, just as before the start, and the fires cleaned in such a manner as to leave the same amount of fire, and in the same condition, on the grates as at the start. The water-level and steam pressure should be brought to the same point as at the start, and the time of the ending of the test should be noted just before fresh coal is fired.

12. **Keep the Conditions Uniform.** The boiler should be run continuously, without stopping for meal-times or for rise or fall of pressure of steam due to change of demand for steam. The draught, being adjusted to the rate of evaporation or combustion desired before the test is begun, should be retained constant during the test, by means of the damper.

If the boiler is not connected to the same steam pipe with other boilers, an extra outlet for steam with valve in same should be provided, so that in case the pressure should rise to that at which the safety-valve is set, it may be reduced to the desired point by opening the extra outlet, without checking the fires.

If the boiler is connected to a main steam pipe with other boilers, the safety-valve on the boiler being tested should be set a few pounds higher than those of the other boilers, so that in case of a rise in pressure the other boilers may blow off, and the pressure be reduced by closing their dampers, allowing the damper of the boiler being tested to remain open, and firing as usual.

All the conditions should be kept as nearly uniform as possible, such as force of draught, pressure of steam, and height of water. The time of cleaning the fires will depend upon the character of the fuel, the rapidity of combustion, and the kind of grates. When very good coal is used, and the combustion not too rapid, a ten-hour test may be run without any cleaning of the grates other than just before the beginning and just before the end of the test. But in case the grates have to be cleaned during the test, the intervals between one cleaning and another should be uniform.

13. **Keeping the Records.** The coal should be weighed and delivered to the fireman in eqnal portions, each sufficient for about one hour's run; and a fresh portion should not be delivered until the previous one has all been fired. The time required to consume each portion should be noted, the time being recorded at the instant of firing the first of each new portion. It is desirable that at the same time the amount of water fed into the boiler be accurately noted and recorded, including the height of the water in the boiler and the average pressure of steam and temperature of feed during the time. By thus recording the amount of water evaporated by successive portions of coal, the record of the test may be divided into several divisions, if desired, at the end of the test, to discover the degree of uniformity of combustion, evaporation, and economy at different stages of the test.

14. **Priming Tests.** In all tests in which accuracy of results is important, calorimeter tests should be made of the percentage of moisture in the steam, or of the degree of superheating. At least ten such tests should be made during the trial of the boiler, or so many as to reduce the probable average error to less than one per cent; and the final records of the boiler test should be corrected according to the average results of the calorimeter tests.

On account of the difficulty of securing accuracy in these tests, the greatest care should be taken in the measurements of weights and temperatures. The thermometers should be accurate within a tenth of a degree; and the scales on which the water is weighed, to within one-hundredth of a pound.

15. As each fresh portion of coal is taken from the coal-pocket, a representative shovelful should be selected from it and placed in a barrel or box, to be kept until the end of the trial, for analysis. The samples should then be thoroughly mixed and broken. This sample should be put in a pile, and carefully quartered. One quarter may then be put in another pile, and the process repeated until five or six pounds remain. One portion of this sample is to be used for the

determination of the moisture and heating value; the other, for chemical analysis.

16. The ashes refuse should be weighed dry, and a sample frequently taken to show the amount of combustible material passing through the grate. To get a representative ash sample, the ash-pile should be quartered as required for the coal.

17. The quality of the fuel should be determined by heat test, by analysis, or by both.

18. The analysis of the flue gases is an especially valuable method of determining the relative value of different methods of firing or of different kinds of furnaces. Great care should be taken to procure average samples, since the combustion of the gases may vary at different points in the flue; and as the combustion of flue gas is liable to vary from minute to minute, the sample of gas should be drawn through a considerable period of time.

19. It is desirable to have a uniform system of determining and recording the quantity of smoke produced. This is usually expressed in percentages, depending upon the judgment of the observer.

20. In tests for the purpose of scientific research in which the determination of all variables is desirable, certain observations should be made which in general are not necessary—such as the measurement of air-supply, the determination of its moisture, the determination of the heat loss by radiation, the infiltration of air through the setting, etc.—but as these determinations are rarely undertaken, no definite instructions are here given.

21. Two methods of defining and calculating the efficiency of the boiler are recommended. They are:

(1) $\text{Efficiency of the boiler} = \dfrac{\text{Heat absorbed per pound of combustible}}{\text{Calorific value of one pound of combustible}}.$

(2) $\text{Efficiency of boiler and grate} = \dfrac{\text{Heat absorbed per pound of coal}}{\text{Calorific value of one pound of coal}}.$

The first of these is the one usually adopted.

22. An approximate statement of the distribution of the heating value of the coal among the several items of heat utilized, may be included in the report of a test when analyses of the fuel and chimney gases have been made.

23. **Record of the Test.** The data and results of the trial should be recorded in a systematic manner, according either to Table 1

(see Vol. XXI, Transactions of the American Society of Mechanical Engineers), or Table 2, taken from those "Transactions."

TABLE 2

Data and Results of Evaporative Test

Arranged in accordance with the short form advised by the Boiler Test Committee of the American Society of Mechanical Engineers, Code of 1899:

Made by.................... on .... boiler, at ....
To determine..
Kind of fuel..
Kind of furnace...
Method of starting and stopping the test (*Standard* or *Alternate*, Arts. X and XI, Code)
Grate surface....................................sq. ft.
Water-heating surface .... " "
Superheating surface............................. " "

Total Quantities

1. Date of Trial.......................................
2. Duration of Trial.................................hours
3. Weight of coal as fired............................ lbs.
4. Percentage of moisture in coal......................per cent
5. Total weight of dry coal consumed.................. lbs.
6. Total ash and refuse.............................. "
7. Percentage of ash and refuse in dry coal.............per cent
8. Total weight of water fed to boiler.................. lbs.
9. Water actually evaporated, corrected for moisture or superheat in steam.............................. "
10. Equivalent water evaporated into dry steam from and at 212° F.................................. "

Hourly Quantities

11. Dry coal consumed per hour................ lbs.
12. Dry coal per square foot of grate surface per hour.................................. "
13. Water evaporated per hour corrected for quality of steam...................... "
14. Equivalent evaporation per hour from and at 212° F............................ "
15. Equivalent evaporation per hour from and at 212° F. per square foot of water-heating surface.............................. "

Average Pressures, Temperatures, Etc.

16. Steam pressure by gauge...................lbs. per sq. in.
17. Temperature of feed-water entering boiler...... degrees
18. Temperature of escaping gases from boiler..... "
19. Force of draught between damper and boiler... ins. of water
20. Percentage of moisture in steam, or number of degrees of superheating..................per cent or degrees

Horse-Power

21. Horse-power developed (item 14 ÷ 34½) . . . . H. P.
22. Builder's rated horse-power . . . . "
23. Percentage of builder's rated horse-power developed . . . per cent.

Economic Results

24. Water apparently evaporated under actual conditions per pound of coal as fired (item 8 ÷ item 3) . . . . lbs.
25. Equivalent evaporation from and at 212° F. per pound of coal as fired (item 10 ÷ item 3) . . . . "
26. Equivalent evaporation from and at 212° F. per pound of dry coal (item 10 ÷ item 5) . . . . "
27. Equivalent evaporation from and at 212° F. per pound of combustible [item 10 ÷ (item 5 − item 6)] . . . . "

If items 25, 26, and 27 are not corrected for quality of steam, the fact should be stated.

Efficiency

28. Calorific value of the dry coal per pound . . . . B. T. U.
29. Calorific value of the combustible per pound . . . . "
30. Efficiency of boiler (based on combustible) . . . . per cent.
31. Efficiency of boiler, including grate (based on dry coal) . "

Cost of Evaporation

32. Cost of coal per ton of —— lbs. delivered in boiler-room $
33. Cost of coal required for evaporating 1,000 lbs. of water from and at 212° F. . . . .

A *log* of the test should be kept on properly prepared blanks containing headings as follows:

TABLE NO. ——

TIME	PRESSURES			TEMPERATURES					FUEL		FEED-WATER		
	Barometer	Steam gauge	Draft gauge	External air	Boiler-room	Flue	Feed-water	Steam	Time	Pounds	Time	Lbs. or cu. ft.	

FIRING

Starting the Fire. The fireman should first ascertain the water-level; as the gauge-glass is not always reliable, on account of impurities, foam, etc., the gauge-cocks should be tried. In a battery of boilers, the gauge-cocks of each should be opened, for the water may not stand at the same level in each. The safety-valve should be raised slightly from its seat. If the fire has been banked over night, open the draughts, and rattle down the ashes and clinkers from the grate. In case the fire has been allowed to go out, a new one may be started if the gauge-glass shows the proper amount of water, and the valves work well.

If anthracite coal is used, first throw a thin layer of coal all over the grate, then place a piece of wood across the mouth of the furnace just inside the door and lay other pieces of wood at right angles to the cross-piece with the ends resting on it. This allows a space under the wood for air. Now throw on coal until the wood is covered. The fire may be started with oily cotton waste, shavings, or any combustible material.

Keep the furnace door open and the draught-plate closed until the wood is burning freely, which causes the flame to pass over and through the coal and to ignite it. The fire is then spread or pushed back evenly over the furnace bars; the furnace door closed; the ash-pit door opened, as the draught requires; and more coal added when necessary. If bituminous coal is used, do not spread a thin layer over the grate bars under the wood.

The fire at the start should be slow, to cause gradual, uniform heating of the water and various parts of the boiler. If steam is raised too rapidly, enormous strains are set up, due to unequal expansion, thereby causing leakage at joints, and perhaps rupture.

If the boiler is of the water-tube type, steam may be raised more rapidly, because the amount of water is less and the joints are usually placed at some distance from the intense heat of the fire.

The fire being started, the method of adding coal depends upon the fireman, the kind of coal, the type of boiler, and the rate of combustion. There are three general methods of firing—*spreading*, *alternate* or *side firing*, and *coking*.

Spreading is accomplished by placing small amounts of coal uniformly over the entire surface of the grate at short intervals. By this method, the coal is thrown just where it is wanted and then not disturbed. The fire should be hollowed in the center; that is, it should be thicker at the sides. Good results are obtained from this method, since the fire can be kept in the right condition at all times, if the coal is of the right sort. During the operation of firing, the door should be kept open as little as possible, or the fire will be cooled by the entrance of cold air. For a short time, while the coal is giving off gas, the draught-plate of the furnace door should be opened, in order that sufficient air may be admitted above the coal to burn the hydrocarbons.

When the *alternate* or *side firing* method is used, coal is spread so as to cover one side of the fire completely at one firing, leaving the other side bright. At the next firing, the bright side is covered. The hydrocarbons given off by the fresh coal are burned by the hot gases from the incandescent coal. This method is superior to spreading, because the entire furnace is not cooled off by the addition of fresh fuel.

Side firing is most advantageous with two furnaces leading to a common combustion chamber. The furnaces are fired at regular intervals with moderate charges of coal, and the draught-plates are opened while the coal is giving off gas.

The two systems described above are best adapted to anthracite coal, since it burns with comparatively little smoke.

With bituminous coal, which is soft and burns with considerable smoke, the *coking method* is used. The coal is piled on the grate just inside the door, and allowed to coke from 15 to 30 minutes. During this time, the hydrocarbons are driven off and burned by the heat from the fire. In order fully to accomplish this, air must be admitted above the grate through the draught-plates of the furnace door. The coke is then pushed backward over the fire, and a new supply placed on the front of the grate. The air admitted prevents the forming of carbon monoxide gas and smoke. At the same time, however, it cools the furnace somewhat and reduces the rate of evaporation; but this objection is not serious unless a boiler must be worked to its maximum capacity in order to furnish the required amount of steam. If this is the case, economy is sacrificed to rapidity, for a low rate of combustion is usually more economical than a high rate.

The necessary thickness of a bed for the best results, is found by experiment. It depends on the draught and the kind of coal used. If the former is strong, and the coal in large lumps, the bed may be thick (about one foot); but if the draught is weak, or if the coal is small, the bed must be thin (about three or four inches), so that sufficient air may pass through. In marine and locomotive work, with forced draught, the bed must be very thick to get a large coal consumption per square foot per hour. With the same draught, bituminous coal can be fired more thickly than anthracite.

After finding from experiment the best thickness for the bed, keep it at that thickness. Always keep the bed of uniform thickness, and never let the fire burn holes in the bed, and do not let the rear of the grate become bare. If a larger amount of steam is required, fire smaller quantities at more frequent intervals. Do not fire a large amount of coal, and wait for the pressure to rise. The firing of fresh coal chills the furnace and temporarily retards combustion. The coal should be fired in small quantities and as quickly as possible. Keep the fire free from ashes and clinkers, but do not clean the fires oftener than is necessary.

Four tools are used for cleaning the fire—the *slice-bar*; the *prick-bar*; the *clinker hook*, sometimes called the *devil's claw*; and the *hoe* or *rake*.

The *slice-bar* is a long, straight bar, with the end flattened. It is used to break up clinkers by thrusting it between the grate and the fire. It is also used to break up caking coal. The *prick-bar* is similar to the slice-bar, except that the end is bent at right angles like a hook. To remove ashes, the prick-bar is run along, up between the grate bars, from underneath. This bar is often made with detachable hook, so that the end may be replaced when burned off. The *clinker hook*, or *devil's claw*, is used to haul the fire forward. The *hoe*, or *rake*, is used to draw out cinders, to haul the fire forward, etc.

In cleaning the fire, the fireman first looks to the water and steam. There should be enough water and sufficient steam pressure to last during cleaning. Then he breaks up the clinkers with the slice-bar, and removes the ashes with the prick-bar. If necessary, he pushes the fire to the rear, thoroughly cleans the front of the grate bars, and then hauls it forward and cleans the back of the furnace bars. Some firemen clean one side at a time, instead of first the front and then the rear. The fire should be allowed to burn down before cleaning; but sufficient fuel, called *chaff*, should be left to start the fire quickly. Before cleaning, partly close the dampers, so that the amount of cold air admitted will be small. For this reason and to prevent loss of pressure, clean as rapidly as possible.

Banking the fire depends upon the condition of the fire, the fireman himself, and the length of time it is to remain banked. First clean and place all the coal in a small space at the bridge; then cover with fresh coal to a depth depending on the length of time the fire is to remain banked. Then close all dampers and open the door. Some firemen cover the front of the furnace bars with ashes.

To start from a banked fire, first examine the condition of the water-level, steam pressure, safety-valves, etc. Then clean the fire with the slice-bar, and rattle down the ashes with the prick-bar. After spreading the coal evenly over the grate, cover with a thin layer of coal, and open the dampers.

CARE OF BOILERS

Any amount of time spent in the proper care of a steam boiler will be amply repaid, for this is of great importance. The boiler, of course, should be so designed and constructed that all parts can be inspected readily; but this is of little benefit unless proper and rigid inspections are made. All internal fittings, such as fusible plugs, water alarms, feed-pipes, and the like, should occasionally be examined to see if they are tight and in good working order. If due care is not given to the boiler, its life will be materially shortened.

The following rules for the management and care of boilers have been established by the Hartford Steam Boiler Inspection & Insurance Company, and should be carefully followed, whether the boiler is insured by the above-mentioned company or not:

1. **Condition of Water.** The first duty of an engineer, when he enters his boiler-room in the morning, is to ascertain how many gauges of water there are in his boilers. Never unbank or replenish the fires until this is done. Accidents have occurred, and many boilers have been entirely ruined from neglect of this precaution.

2. **Low Water.** In case of low water, cover the fires immediately with ashes; or, if no ashes are at hand, use fresh coal, and close ash-pit doors. Do not turn on the feed under any circumstances, nor tamper with or open the safety-valve. Let the steam outlets remain as they are.

3. **In Case of Foaming.** Close throttle, and keep closed long enough to show true level of water. If that level is sufficiently high, feeding and blowing will usually suffice to correct the evil. In case

of violent foaming, caused by dirty water or by change from salt to fresh water or *vice versa,* in addition to the action above stated, check draught, and cover fires with fresh coal.

4. **Leaks.** When leaks are discovered, they should be repaired as soon as possible.

5. **Blowing Off.** Clean furnace and bridge wall of all coal and ashes. Allow brickwork to cool down for two hours at least before opening blow-off. A pressure exceeding 20 lbs. should not be allowed when boilers are blown out. Blow out at least once in two weeks. In case the feed becomes muddy, blow out six or eight inches every day. When surface blow-cocks are used, they should be frequently opened for a few minutes at a time.

6. **Filling Up the Boiler.** After blowing down, allow the boiler to become cool before filling again. Cold water pumped into hot boilers is very injurious, from the sudden contraction set up.

7. **Exterior of Boiler.** Care should be taken that no water comes in contact with the exterior of the boiler, either from leaky joints or from other causes.

8. **Removing Deposit and Sediment.** In tubular boilers, the handholes should be frequently opened, all collections removed, and fore-plates carefully cleaned. Also, when boilers are fed in front and blown off through the same pipe, the collection of mud or sediment in the rear end should be removed frequently.

9. **Safety-Valves.** Raise the safety-valves cautiously and frequently, as they are liable to become fast in their seats and useless for the purpose intended.

10. **Safety-Valve and Pressure-Gauge.** Should the gauge at any time indicate the limit of pressure allowed by the insurance company, see that the safety-valves are blowing off. In case of difference, notify the company's inspector.

11. **Gauge-Cocks, Glass Gauge.** Keep gauge-cocks clear and in constant use. Glass gauges should not be relied on altogether.

12. **Blisters.** When a blister appears, there must be no delay in having it carefully examined and trimmed or patched, as the case may require.

13. **Clean Sheets.** Particular care should be taken to keep sheets and parts of boilers exposed to the fire, perfectly clean; also

all tubes, flues, and connections well swept. This is particularly necessary where wood or soft coal is used for fuel.

14. **General Care of Boilers and Connections.** Under all circumstances, keep the gauges, cocks, etc., clean and in good order, and things generally in and about the engine-room in a neat condition.

15. **Getting Up Steam.** In preparing to get up steam after boilers have been open or out of service, great care should be exercised in making the manhole and handhole joints. Safety-valve should then be opened and blocked open, and the necessary supply of water run in or pumped into the boilers, until it shows at second gauge in tubular and locomotive boilers; a higher level is advisable in vertical tubulars as a protection to the top ends of tubes. After this is done, fuel may be placed upon the grate, dampers opened, and fires started. If chimney or stack is cold and does not draw properly, burn some oily waste or light kindling at the base. Start fires in ample time, so that it will not be necessary to urge them unduly. When steam issues from the safety-valve, lower it carefully to its seat and note pressure and behavior of steam-gauge.

If there are other boilers in operation, and stop-valves are to be opened to place boilers in connection with others on a steam-pipe line, watch those recently fired up, until pressure is up to that of the other boilers to which they are connected; and, when that pressure is attained, open the stop-valves very slowly and carefully.

INDEX